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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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MATERIALS AND METALLURGY SUBCOMMITTEE MEETING

CALCULATION OF NEUTRON FLUENCE DG-1053

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PUBLIC MEETING

Nuclear Regulatory Commission

Room T2-B3

Two White Flint North

11545 Rockville Pike

Rockville, Maryland

Thursday, November 16, 2000

The above-entitled meeting commenced, pursuant to notice, at 8:33 a.m.

MEMBERS PRESENT:

WILLIAM SHACK, Chairman

DR. THOMAS KRESS

DR. ROBERT SEALE

ALSO PRESENT:

DR. NICHOLAS TSOULFANIDIS
MR. NOEL DUDLEY
DR. NILESH CHOKSHI
MR. BILL HOPKINS
DR. SHAH MALIK
MR. BILL JONES
MR. LAMBROS LOIS
DR. JOHN CAREW
MR. TUCKER WARSHAM

P R O C E E D I N G S

[8:33 a.m.]

CHAIRMAN SHACK: The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Materials and Metallurgy. I am Dr. William Shack, Chairman of the subcommittee.

ACRS members in attendance are Thomas Kress and Robert Seale. Also in attendance is ACRS consultant, Nicholas Tsoulfanidis.

The purpose of this meeting is for the subcommittee to hear presentations by the staff concerned the proposed final Regulatory Guide on Calculation and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence.

The subcommittee will gather information, analyze relevant issues and facts and formulate proposed positions and actions as appropriate for deliberation by the full committee.

Mr. Noel Dudley is the cognizant ACRS staff engineer for this meeting.

The rules for participation in today's meeting have been announced as part of this notice of this meeting previously published in the Federal Register on October 25th, 2000.

A transcript of this meeting is being kept and will be made available as stated in the Federal Register Notice.

It is requested that speakers first identify themselves and speak with sufficient clarity and volume so they can be readily heard.

We have received no written comments. A representative of Framatome requested the opportunity to make a statement at the end of the meeting.

The ACRS examined Draft Regulatory Guide DG-1025, Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence in 1993 and requested the opportunity to review the proposed final version after public comments were reconciled.

Subsequently, DG-1025 evolved into DG-1053. The staff briefed the subcommittee on the status of DG-1053 during its April 15th-16th, 1997 meeting. More recently, DG-1053 evolved into the final -- or into the proposed final Regulatory Guide we are reviewing today.

During this evolutionary process, stakeholders had opportunities to provide comments on the different versions of the Regulatory Guide. Today we will hear presentations regarding the proposed final Regulatory Guide.

We will now proceed with the meeting, and I call upon Dr. Nilesh Chokshi, Chief of the Materials Engineering Branch, to begin.

DR. CHOKSHI: Good morning and thank you, and let me, I think as Dr. Shack mentioned, my name is Nilesh Chokshi. I am the new Branch Chief of the Materials Engineering Branch, just about three months, and OPM placed the position last month.

So, as such, this is my first presentation to this august body, and as it will happen, the subject matter is neutron fluence calculation and dosimetry, not the subjects I would have chosen for my first encounter. Stresses and strain is more of my language, but luckily, I have experts which are going to take you through the evolution and the technical bases -- the technical positions and the bases.

Then also we have an NRR expert here, so I think, you know, we are ready to explain the bases.

Why I am here is really to, you know, tell what we want to accomplish, why we here. And I think you already touched on some of those aspects. I think that as you pointed out, this process has been underway for quite some time, and I think we are ready here to really go, follow with the final publication of the final guide. And what we would like to do is go over the technical positions, discuss the bases for those positions and some of the implementation aspects.

During that process, we also want to discuss some of the major public comments received, particularly on the last job for DG-1053, how we have addressed that, what changes have taken place because of those comments. And, also, describe to you when we have not -- you know, why we have chosen not to accept certain comments.

I am going to touch very briefly on the interactions which have taken place with the public, and I think, as both the presentations, you will see more, you know, what was the involvement, to what extent.

We are here to seek, starting with this subcommittee, the ACRS approval to go forward and publish the final Regulatory Guide. And I think we are the stage that the guide is ready to go forward.

Of course, I will just take it briefly and discuss. The guide, it basically standardizes the methods for the fluence calculations and use of the dosimetry.

CHAIRMAN SHACK: Excuse me. I really don't know a whole lot about this subject. But there is an awful lot of references to consensus standards that seem to cover much of this ground. Is there a reason you need your own Regulatory Guide rather than relying on consensus standards?

MR. LOIS: The answer is yes. I am Lambros Lois, Reactor Systems Branch. The reason is that because of the existence of a variety of methods and techniques, people have been using them to their own advantage, so to speak. In other words, they use whatever produces the best results.

This guide is based on --

CHAIRMAN SHACK: Well, that's what we want, the best results, right.

MR. LOIS: Well, results which satisfy specific objectives. The fundamental, the basis or the premise for this guide is the requirements of GDC-1430 and 31 which describe qualitatively what are the requirements that should be fulfilled for the materials and, therefore, for the neutron fluence. So that is the reason why we need to have a standard rule of flux.

As a matter of fact, there was a great deal of confusion that persists even today -- well, not confusion, but I should say created confusion as to what is the appropriate way of doing it, and that expresses the staff's intent.

DR. CHOKSHI: Yeah, I think the second bullet was basically that there is a wide variety of the existing methods and guidance is needed because this basically applies to a number of regulatory requirements, Appendix G and H of Part 50, 10 CFR 50.61, the whole PTS issue. So that, I think, is standardized approach, or at least a known approach will be a much better, I think, situation.

And you went over the brief history, you know, as you said, the initial approach was started in '93. Research received, it was only later in '92, and there have been several drafts. I think when John Carew goes through that, you will see why this has taken -- how the scope has changed over the period, and there several public comments periods, you know, we have sent several drafts out for the public comments, a number of public meetings.

The last round of comments was on the DG-1053, which we received the comments in May and then I think since that, we have been revising the guide. And I think at this point in time the guide is ready. We have been also discussing with NRR and OGC and other people. And if everything goes according to the plan, I think we should be able to publish the guide probably next year, hopefully, sometime in the spring.

So what I want to do is, with this brief introduction I think what I will propose to do is --

CHAIRMAN SHACK: Let me ask just one other question now.

DR. CHOKSHI: Sure.

CHAIRMAN SHACK: Do you think this is going to impact those people that have sort of potential PTS problems? I mean Beaver Valley and Palisades are the ones that come to mind. You know, will the changes introduced by the guide affect those calculations?

DR. CHOKSHI: I will have Lambros --

MR. LOIS: Yes. Again, this is Lambros Lois. We essentially have been working for the last year or two out of the Draft Guide. So essentially both these two plants, as well as others, have adopted the methods that are promulgated there. The only difference is that is what left to be done is just make it official.

DR. CHOKSHI: Yeah. I think that is important and I think my understanding is that people have been already using a number of the benchmark problems, a number of things which have been already out.

CHAIRMAN SHACK: This is not a --

DR. CHOKSHI: You know, the knowledge is out there and people are already applying it, I think. And the reason I say it is, you know, Dr. Carew is going to make a presentation, but I think I will have Bill Jones of Research and he is going to give an overview sort of, and then John is going to talk about the details of the technical positions, also how the benchmark problems and the NUREG, and then public comments. And I think in the end, we will come back and Bill will close, go over the summary and the schedule.

So, if there are no more questions, I think I will ask Bill to come and give his presentation.

MR. JONES: I am Bill Jones, and I have been the Project Manager on this Draft Guide and Reg. Guide for about a year, year-and-a-half, and so what I really want to do is give you an overview before Dr. Carew gets into the details. That is really why I am here.

And as your slides indicate, I want to talk about a couple of things as a way of bridging into what John is going to talk about. The objectives of the Reg. Guide and then the contents of the guide. And I think if I go over the contents, it will -- the guide, it is not a small document, so my objective would be to sort of stress what is in there and sort of break it out into three parts, because that is really what is there.

So, our objectives were and are to provide methods and describe those methods and make them consistent for both calculation and dosimetry, for both calculation and measurement. And if a licensee chooses to use these, then these methods would satisfy our regulations.

And we have detailed descriptions of the fluence calculations, discrete ordinates Monte Carlo, how dosimetry measurements can be used, and the procedures for qualification and determination of uncertainty.

And I already talked about measurement, but there is a lot of information in there about -- there is a substantial amount of information in there about dosimetry.

The document itself is really -- the regulatory position is really in three parts. The neutron fluence calculational methods, and we talk a lot about that, we lay that out in terms of how you would construct the problem and where you get your cross-section. We talk about neutron sources, which are pretty important to get from the outside of the core fuel to the vessel. We talk about qualification and uncertainty.

Okay. Part 1 is fluence calculational methods, Part 2 is fluence measurement methods. And so we talk about dosimetry. We give a lot of cautions in the dosimetry and we talk about dosimetries that can be used.

In the last part, in the sort of technical part is reporting. We talk about how we would expect licensees to make this information available to us, to the staff. And not part of the regulatory position, but also we talk about implementation, how the staff plans to use the information that the Draft Guide talks about.

So there's three parts really, there's calculational, there's measurement, and then there's reporting. So those are the three main parts, the semi-technical parts of the guide.

That's really all I had to say. I am really trying to outline it, lay it out for you so that John can get into the details.

The last slide in the smaller package talks about summary, and we will come back to that at the end of the staff presentation.

Do I have any questions?

CHAIRMAN SHACK: Is the fluence calculation that you do here consistent with what is assumed in 1.99 when you are looking at toughness variations through the wall and, you know, there is an implied fluence variation built into that?

MR. JONES: Lambros, do you want to --

MR. LOIS: Yes. This is Lambros Lois. This guide is a supplement to 1.99. 1.99 deals with the materials end of it, and this proposed guide deals with the fluence portion of that. The assumed value is what is in this guide. In other words, the quality or the rigor, or the methodology, the assumptions in 1.99 are listed in this guide.

CHAIRMAN SHACK: Okay. But isn't there an implied fluence variation built into 1.99 when you are looking at the throughwall variation of the fluence? At the inner wall, you start here.

MR. LOIS: Yes. Yes. Right.

MR. JONES: The calculational method that we are really talking about here, in parallel with 1.99, says, how do I get my fluence at the vessel wall? 1.99 has the exponential coastdown, whatever -- I am searching word and I can't find it. The exponential -- the reduction in the fluence as you go through the wall, that it is explicitly listed in 1.99, right.

So, in 1.99, you need to use still that --

CHAIRMAN SHACK: Well, I guess that is my question. You have this rigorous method for calculating the fluence. Why do you then use a different method in 1.99?

MR. JONES: Well, 1.99, we are thinking about -- Shah, do you want to talk about that?

DR. MALIK: Talk about the PTS reactivities. What you are talking about, -- this is Shah Malik.

MR. JONES: Attenuation, right.

DR. MALIK: Attenuation factor. Shah Malik, Office of Research, Materials Engineering Branch. You are talking about attenuation factor, that is an approximate exponential minus .24X there. That is an approximation which, when we do the tail -- calculation, we have found that, at least for the first quarter thickness of the vessel, that attenuation is very close or just a little less than the found from this Reg. Guide.

CHAIRMAN SHACK: Okay. So it is consistent?

DR. MALIK: It is consistent. And as you go further towards the outer surface, the attenuation factor there is I think lower than what you see here. So it is more conservative, exponential .24X is more -- minus .24X is more conservative than you find in front here.

MR. JONES: We have taken the attenuation and we have laid the actual calculation right on top of it. And the description Shah gave is correct, I mean that is a good description. They are not inconsistent, they are not very inconsistent.

CHAIRMAN SHACK: Are there any more questions? Are there any more questions?

[No response.]

CHAIRMAN SHACK: And I just want to say we appreciate your time and letting us come talk to you about this. And so without trying to bridge into it and dividing the Draft Guide into three parts, I am going to introduce Dr. John Carew from Brookhaven, who has been involved in the Draft Guide since it was started.

DR. CAREW: I'm John Carew, and I will be discussing, I will be reviewing some of the details of the Regulatory Guide DG-1053 on Calculation and Measurement of Pressure Vessel Fluence. I will also be discussing the resolution to the comments we received from industry in May and then I will finally be discussing the NUREG report which describes the pressure vessel fluence benchmark problems.

Let me first note that the reactor pressure vessel fluence is required for the determination of vessel embrittlement and lifetime and the vessel fluence is used to determine the adjusted reference temperature for the nil-ductility transition, RTNDT, and also the fluence is required input for the PTS Rule 50.61 for the termination of the reference temperature for PTS.

The problem with the fluence stems from a combination of several factors, and this includes, first of all, the neutron fluence undergoes -- and this is the key item, the problem, the neutron fluence undergoes several decades of attenuation between the core and the pressure vessel.

And here in the next slide we have, this is the pressure, here is the core, barrel, thermal-shield and pressure vessel, and as the neutrons propagate from the core out to the vessel inner wall, they undergo three decades of attenuation. And as shown in the next slide, this is the group 1 flux, the flux in the group right around 1 MeV. You can see the flux is basically flat. The neutron flux is basically flat in the core region and drops dramatically as it goes into the water region. There is a spectral change right in front of the steel region, the core barrel, it shifts upward, then drops again down into the spectral shift here in front of the thermal-shield in the vessel. But you can see it drops three or more than three orders of magnitude, and that is the problem.

As a result of this strong exponential attenuation, the calculation of the fluence is extremely sensitive to the material and geometry representation of the core and vessel internals, the core and neutron source, and the transport and numerical schemes. As a result, to get an accurate prediction of the fluence, you require detailed, multi-group, multi-dimensional calculations.

Now, in practice, in performing these calculations, to facilitate these calculations, there are a wide range of fluence method approximations and methods that are used, and these include, for example, cross-section sets, the treatment of the core neutron source, the axial synthesis treatment and the various computer codes that have evolved over the years to simplify this problem.

And, in addition, because of the limited number of surveillance capsule and benchmark data, and the uncertainty in these data, it is very difficult to determine what the accuracy of these fluence predictions are to benchmark them. And this is complicated by the fact that you really need an accurate prediction of the fluence for several of the vessels because of the limited margin to the NIIRTPTS. And this is the basic problem, and this problem is addressed by the Reg. Guide which provides procedures and methods for doing measurements and calculations that determine the fluence to within an accuracy of the order of less than 20 percent, which is the requirement for the PTS rule.

DR. SEALE: John.

DR. CAREW: Yes.

DR. SEALE: I started my career in this business doing shielding calculations, and I have always had a considerable amount of disdain for those people who look down their nose at an uncertainty of a factor of 10 in a shielding calculation, and not appreciate the fact that you have this several orders of magnitude of degradation due to the attenuation.

By looking back on your sketch, and I realize that is all it is, the neutron flux versus radius.

DR. CAREW: Right.

DR. SEALE: The cavity is the region beyond the outside of the core?

DR. CAREW: Right, that is outside the vessel.

DR. SEALE: Yeah, I mean outside the vessel. There is some exponential attenuation that is taking place in there.

DR. CAREW: Well, it is really not -- there is no material, it is a vacuum basically. There was some air in there.

DR. SEALE: I'm sorry, there is some --

DR. CAREW: Geometrical attenuation.

DR. SEALE: Geometric attenuation, yes.

DR. CAREW: Exactly, right. Yeah, and it is very slight, it is small compared to the material attenuation, but it is still there, and the calculation reflects that, but on this scale you really can't see it. But you are exactly right.

DR. SEALE: Yeah. Yeah. Essentially maybe --

DR. CAREW: 1 over R squared or --

DR. SEALE: Yeah. Well, as a matter of fact, if you multiplied the flux by R squared --

DR. TSOULFANIDIS: It is not 1 over R square. Neutrons are streaming out.

DR. CAREW: Well, it is cylindrical geometry, you know.

DR. SEALE: I appreciate that. Well, it is 1 over R, I'm sorry, roughly. In the cylindrical geometry, it is pretty close.

But the point is that that is not exactly flat.

DR. CAREW: Exactly, right.

DR. SEALE: Okay.

DR. CAREW: Okay. Let's see. So now, all right, let's see. So in the following, I will be discussing the Regulatory Guide, reviewing some of the major points in the Regulatory Guide. I will be discussing how we resolve the recent May NFE comments and the benchmark problem analyses.

Okay. Let me start with the Regulatory Guide. The Regulatory Guide was developed by the Materials Engineering Branch of the Office of Nuclear Regulatory Research by Brookhaven National Laboratory with input from

NIST and from Oak Ridge.

The purpose of the guide was to document calculation and measurement methods for determining pressure vessel fluence that are acceptable to the NRC. The scope included vessel determination for input to the PTS rule and to the Reg. Guide 1.99 and Appendix G.

The Reg. Guide included a very detailed description of the fluence calculation and measurement methods, procedures for qualifying the calculations and measurements, a table of specific modeling, dosimetry qualification and reporting requirements, and it requires the calculation of the benchmark problems in NUREG-6115.

In calculating the fluence, the primary calculational tasks, as you might expect, or the major tasks are, first, the determination of the geometrical and material composition data. Second -- of the configuration, the vessel out through the barrel, from the core out through the barrel and downcomer into the vessel. The second step is to determine where -- how many neutrons are we producing. And that is the determination of the core neutron source, which is relatively complicated. And, finally, the propagation of a neutron source in the core out to the inner wall of the vessel. These are the three major steps in the calculation.

CHAIRMAN SHACK: John, how do you average that? I mean, you know, the fuel is burning during -- as you rearrange the core and as you reload fuel. What averaging do you do in the time variation here?

DR. CAREW: Well, first of all, you have to recognize that 85 percent of the source is coming from the peripheral -- the bundles in the periphery of the core. And what you really need to know is what is the power -- well, basically, what is the power in each one of those assemblies. And you can integrate that over each cycle and determine what the power produced.

Then the next question is, where is the power -- from which isotopes if the power being produced? And you get that from fairly -- a fairly good reading on that from the standard cell the physics people use, the core designers use in the cell calculation. They can tell you you have 50 megawatts or a certain number of megawatts coming from a specific bundle, they can tell you that 50 percent is coming from the U-235, 34 percent is coming from the plutonium-239, et cetera. So you can determine which isotopes the power is coming from, and then, given that, you know what the -- you can determine, you knew what the nu over kappa is, and which it tells you how many neutrons per MeV are being produced. And then, finally, there is good data on how those neutrons are distributed in energy from the neutron spectra.

So, you first sum that up over the cycles. Now, any point on the vessel really doesn't see one bundle, it sees several bundles, probably three or four bundles on the periphery. So have the benefit of, you know, in addition, you are adding out over many cycles, so you are not that sensitive to a given particular bundle. You may be high in one cycle, but low in the next cycle.

But you touched on it -- well, there is another complication in the fact that there is a gradient on the periphery of the core, the peripheral, the fuel, the pins, you know, there is a gradient on the bottom, on the outside of the core that doesn't go off abruptly like a step function, and you have to account for that also. There is a benefit for that because the fluence is using it, treating it as a step function would over-predict the fluence. So you have to account for that. And the pin powers are -- those are well determined.

But that is an excellent question, because it turns out that one of the major uncertainties in the fluence prediction is the source. Basically, there are two dominants. In the calculation of the fluence, there are really two important uncertainties. One of them is the source. How much power is being produced in those peripheral assemblies? And there is a substantial, as you might -- as you probably understand, there is a substantial uncertainty in that prediction.

And, secondly, in many vessels -- in some vessels, there is some uncertainty in the inside diameter of the vessel. And because of the strong exponential attenuation of the fluence, any displacement of that vessel introduces a significant amount of uncertainty. So that is the other major uncertainty in the calculations. That's how you determine what the source is and what the powers, you have to sum that over each cycle.

CHAIRMAN SHACK: So the geometry is actually a major source of uncertainty.

DR. CAREW: Yeah, exactly, and it is because the -- the problem would go away if everything was flat.

Okay. Right. Now, let me go to the next slide. This slide is the -- I just might say that there are two methods that the guide allows to the calculation to be done. You can use a discrete ordinates transport method or you can use Monte Carlo. And I will just, I will start with the discrete ordinates method.

And, as I mentioned before, this is a flow diagram of the calculation, and the calculation really takes place by this code here, DOT, discrete ordinates transport, DOT. There are later versions of that called DORT and DOORS, but they were basically the same code. And this is the code that calculates the fluence, the transport of the neutrons from the core to the vessel.

Now, to do that calculation, you need, first of all, the input of the core geometry -- the system geometry, and that is fed in here from the left, the core internals vessel geometry. And then, secondly, you need to know what is in those regions, what material is in those regions, and that comes from this region, from this component here. You feed in the component material composition, which is combined with the microscopic neutron scattering cross sections. They are fed into the code and these determine the strength of attenuation in each one of the regions.

And then finally you need to know the source. You need to know how many neutrons are being produced in the core. And that comes from a combination of, first of all, the cycle-dependent assembly pin and powers and exposures. You need to know the exposure because, as the exposure accumulates in the bundle, you get more and more plutonium present and plutonium produces more neutrons per energy MeV and it produces a harder, faster neutron, so they propagate more readily to the vessel. And, consequently, higher exposure bundles are more of a concern because they produce a higher fluence.

So you need to know the exposure and then also you take the amount of neutrons, the power and exposure being produced, combine that with a spectrum, the energy distribution of those neutrons. That is fed into this code, and it transports the codes out to the vessel.

There is one additional complication, this calculation is so complicated that actually you typically just do a planar calculation in R theta geometry, and then you do an axial calculation, and then you do a synthesis to combine then and that is the step here. So that is basically how the calculation is carried out.

CHAIRMAN SHACK: Is your technology robust enough that if somebody, you know, starts burning mixed oxide, that you change the inputs, obviously, but have you changed the basic technology here? Is the guide still valid?

DR. CAREW: As you pointed out, you change the input. The exposure would be more and, consequently -- well, not just exposure, but, as I mentioned, with high exposure, you get a higher inventory of plutonium. And, as a matter of fact, after two or three cycles, the fraction of plutonium being -- the fraction of fissions in the plutonium is like 70 percent. So for high, we only put -- let me write that down, 60 percent, so with a high burnup bundle, you are getting 60 percent of your fissions in plutonium already.

Now, if you go to mixed oxide fuel, you probably would go even higher, but all the arithmetic and all the mechanism and all the algorithms are all the same basically. There would just be a little more plutonium.

DR. SEALE: It starts sooner.

DR. CAREW: It starts sooner, right. And so that is the basic calculational scheme. And I will just say in passing that one of the comments in the round two comments was that they wanted not only discrete ordinates capability, they wanted us to address how you do Monte Carlo calculations.

Go ahead.

CHAIRMAN SHACK: For one second. When I looked at the public comments, most of them seemed to be more on the clarification order, and then I came to the one from the professor at Penn State who said the whole thing wouldn't work for BWRs.

DR. CAREW: I will discuss that.

CHAIRMAN SHACK: Okay. You are going to discuss that.

DR. CAREW: Right. Right. So one of the round two comments, I guess that was in '96, was to expand the scope of the guide, and this was a substantial expansion, for a couple of reasons. First of all, at the time that it was suggested, Monte Carlo was really not being used for this calculation, for various reasons. And so it was new technology, it had never been accepted by the NRC really, but we expanded the scope and have included Monte Carlo in both the Regulatory Guide and also in the benchmark problems.

But, in any case, the Monte Carlo capability is really not very much different than the discrete ordinates. It is basically the same. The only thing different is this code here, the transport of the neutrons from the core to the vessel is carried out, instead of a deterministic discrete ordinates space energy mesh type of calculation, it is carried out in a statistical manner where neutrons are started off and their trajectories are followed as they go from the core out through the various scattering events, out to the vessel inner wall, and the tallies are summed and an estimate of the fluence is determined.

The advantage, of course, is that all the surfaces in the problem are modeled exactly and the geometry is a true, high fidelity, exact fidelity, basically, representation of the geometry. Of course, the complication is that because of this attenuation in the core, that you are dropping by three decades, it takes -- you have to start off a thousand neutrons in the core before one will eventually arrive in the vessel. They all disappear before they get there, which means the statistics, if you run a calculation, the variants in your edit will be you will never get any neutrons. There will be so few neutrons that your statistics are very, very poor, and that is the complication. So you win, but you also lose.

So, anyway, this is basically -- this has all been included in the guide and in the benchmark problems.

DR. TSOULFANIDIS: John

DR. CAREW: Yes.

DR. TSOULFANIDIS: Nick Tsoulfanidis, ACRS consultant. You might mention one advantage of Monte Carlo is you may have continuous energy cross sections, however, whatever uncertainty you have the source, it is the same for both methods.

DR. CAREW: Exactly. Right. Yeah. That's a good point. One thing I didn't mention, the advantage of the Monte Carlo is that not only do you get a sense of doing it statistically, you can include the exact cross sections continuously. So if you have an event, you can sample from the energy and find out what the energy was and go look up the cross sections at that specific energy, where in a discrete ordinates calculation, you have to assume that you break the energy range into discrete intervals.

And it turns out that that approximation is not -- with the number of groups that we use, we can get a pretty good idea of what the error is by going from a large number of groups down to smaller groups and see how the error, how it changes.

So the technology is well developed and we have got -- we know the values, or we know where all the approximations are.

Okay. The next item I would like to discuss is the qualification. We have these methods, and now, as required by Appendix B of 10 CFR 50, the methods must be qualified. And how do we assure that they are valid and accurate?

The guide requires that this take place in two steps basically. The first step would be do an analytic determination of the uncertainty. And that means we take the computer code and we perform some numerical sensitivity calculations where we perturb each one of the input parameters and see what the change in the edit is, the fluence is. And once we know what all the sensitivities are, and, of course, we would be focused on the vessel diameter, what the sensitivity to the vessel diameter change is, and, of course, what the change in the source is, what the effect is. And there is other uncertainty as well, but they are the major ones.

So we determine what the sensitivity is, and then, using that sensitivity, we combine that with estimates of what the source uncertainty would be and what the sensitivity -- what we think the vessel diameter uncertainty is. And I might add that for some vessels we have a lot of measurement data, and we have a very good idea what the uncertainty in that vessel, you know, they go through the vessel, around the circumference of the vessel and take various measurements, and we have looked at those, and you have a lot of data. You can get a mean value, you can get a standard deviation. You can get an idea of what the uncertainty of that vessel diameter is. Other vessels, we have very little data. So it varies from plant to plant.

But if we have a lot of good data, there is a very good indication of what the uncertainty would be. And so this is one technique.

But we have to recognize there are some situations where we have very little data and this would not provide a good estimator of what the fluence uncertainty is. So we have to do more than one -- have more than one path.

And this other path is basically comparing predictions to benchmarks. And there's several types of benchmarks. We have some plants have extensive operating dosimetry surveillance capsule data. So, for those plants, we would be looking at dosimetry data.

Also, there are available some pressure vessel simulator experiments, the PCA and other experiments that have been done, that also provide extensive dosimetry and good measurements, so that is another path.

And then finally we have a benchmark problem, NUREG-6115, which provides a definition problem, a well defined, complete problem to calculate and reference solution.

So we would go through this qualification procedure and we would determine what the uncertainty would be, and that is the qualification path.

Now, for the PTS rule, we should show that the uncertainty has to be less than 20 percent. Now, in the next slide. Now this is a figure that was suggested by one of the commenters from Bechtel, actually Bill Hopkins. And what this does, in the guide, the PTS rule requires an uncertainty of 20 percent. And what do we do if the uncertainty is greater than -- what does a licensee do if the uncertainty is greater than 20 percent?

Well, this diagram shows clearly, describes how we address that situation. If the uncertainty evaluation, if the uncertainty is less than 20 percent, we just proceed and we use the calculated value and apply, if there is a bias that we want to apply, we can just multiply by the bias, and we get the result.

The complication occurs if the uncertainty is greater than -- well, the uncertainty is greater than 30 percent, the guide is no longer applicable. This would require a case-specific review. On the other hand, if the uncertainty is between 20 and 30 percent, we have the option where you can reduce the fluence value by an amount that would preserve the probability -- it would ensure that the probability of an under-prediction is not increased. So in this case there is a penalty applied to the fluence.

DR. KRESS: What is the basis for the selection of those percentage acceptance values?

DR. CAREW: Which, the 20 percent?

DR. KRESS: Any one of them.

DR. CAREW: Well, okay, the 20 percent is part of the -- is what was assumed in determining the PTS criteria rule. They allocated 20 percent uncertainty for the fluence, so that is where the 20 percent comes from.

Now, the 30 percent is a number that we think this is a reasonable -- if someone has a 30 percent uncertainty, this is a reasonable uncertainty. It may not be that surprising, and, therefore, we allow them to use that calculation, but they must -- the value must be reduced. The value of the fluence must be reduced by an amount such that the probability of an under-prediction is not increased. And then 30 percent, above 30 percent, we feel that that calculation really requires a special review, it is outside the scope of the guide.

MR. LOIS: John. This is Lambros Lois again. It is rather of historical significance. Way back in the early '80s when we were putting together 10 CFR 50.61 with the PTS rule, we were required to have -- to come up with an uncertainty. At that time, both calculational tools and measurements were not -- measurement database was not available. So we utilized, actually, it was John who did that, utilized sensitivity calculations, and we concluded that 20 percent would be a reasonable uncertainty.

That was folded into the uncertainty or in the penalty, if you wish, term on 50.61, on 10 CFR 50.61, and that is where it stayed and ever since has been part of the calculation. And nowadays both databases are wider and have more data, and the calculation techniques are accurate. So we can do better, but because it was incorporated in the original 50.61, it still stays there. So that is the reason why it is 20 percent.

DR. CAREW: Okay. All right. Let's see. The next slide is the measurements and then, let's see. Okay.

So, in summary, --

CHAIRMAN SHACK: A question.

DR. CAREW: Go ahead.

CHAIRMAN SHACK: If you can do better, do you get any credit?

MR. LOIS: In the uncertainty, you can do better, yes. You get credit automatically because you have a smaller uncertainty. Now, unfortunately, the interns of the penalty or -- you don't, because it has to be folded with the materials and that is a mess. I mean, you know, it is very difficult to do that.

DR. TSOULFANIDIS: What is the basis for taking the second step, the 30 percent, and now saying if it is 20 and one treatment 20 or less and one treatment 20 and above?

MR. LOIS: The gentleman who proposed that, and we have adopted it, is sitting in the back there, Bill Hopkins. It is just an intuitive number, just an educated guess. You feel that the 30 percent is way too out, so we don't want to continue with that calculation. There is no specific technical reason for that, like the 20 percent.

DR. CAREW: But we ensure, if they are in the range from 20 to 30, that the probability of an under-prediction of a fluence is maintained. So we apply a penalty to ensure that when you are in that range, that things are not degenerating.

Okay. In summary, the Regulatory Guide provides a best estimate rather than a bounding fluence. In other words, all the assumptions that go into the Reg. Guide were carefully made so that it is a best estimate, we are not doing any bounding calculations. If the guide is followed, the accuracy should be less than 20 percent 1 sigma, and the energy range is from 15 MeV down to .1 MeV. The qualification is by benchmarking and uncertainty analysis.

The applicability of the guide includes -- well, first of all, it provides input for Appendix G and Reg. Guide 1.99, the PTS rule. It is applicable to both PWR and

BWR core vessel geometries and fuel designs. I might add that initially, back in -- we did the 1025, the initial Reg. Guide was not really applicable to BWRs, but in the round two questions in '96, we were asked to include that, and that, again, was a substantial increase in the scope of the guide. But that has been included. So now we are applicable to both BWR and BWR cores and fuel designs. And, importantly, the guide is also applicable to those core designs that are constructed for fuel -- vessel fluence reduction, such as the low leakage cores, the partial link shield assembly cores and the life extension calculations, and also the mixed oxide fuel, now that you mention that.

I was going to review the status of the guide. The initial release was in 1993. At that time we had the ACRS subcommittee and committee meetings. We met with the CRGR. We released the guide for comment. We had a set of round one comments that were evaluated and incorporated in the guide.

We had a follow-up meeting with industry in September 18th, '96 where we reviewed the comments and the resolution. At this meeting, I mentioned there were several changes in the scope of the guide. The Monte Carlo was added to both the guide and the NUREG problems report, and also the BWR was incorporated.

In September, and then in September '99, a year ago last September, we met again with industry. At this time industry requested that we provide the resolution of comments document which provides the basis for the resolution of all our previous round one and round two comments.

We provided that to the stakeholders and industry in March 2000, and we received the industry comments in May 2000. And we completed the evaluation of these comments in August and have incorporated all the comments into the guide. So the guide, as it stands today, incorporates all the latest comments.

DR. KRESS: What does that mean?

DR. CAREW: Excuse me. Go ahead.

DR. KRESS: When you say incorporates all the comments, does that mean you looked at them and decided whether it is valid?

DR. CAREW: Right. And I will go into that in detail. I will discuss how we did that.

DR. KRESS: Okay.

DR. CAREW: And we intend, or we hope to intend, or we expect to release the guide in early 2001.

Okay. Let's see. Now, I will get into the resolution of comments. Let's see. We received comments from the Nuclear Energy Institute, Penn State University, and Bechtel Power, Bill Hopkins, and an organization called

Don't Waste Michigan. This is a small organization -- I am not so sure it is small, but it is an organization that is focused on one specific reactor.

MR. JONES: I need to interject one thing here. The Bechtel Power Corporation, those comments were received informally. They were reviewed to the same degree and treated the same. And, in fact, John mentioned that the figure that was incorporated due to those comments, you didn't get those in your package because they were submitted informally. I needed to point that out to you at this point. Excuse the interruption.

DR. CAREW: Okay. The comments concerned editing, organization, methods and qualification. The comments included recommendations to both tighten and relax requirements. Okay. And the resulting changes and additions have been included in the latest version of the guide.

I didn't want to go -- it is really unwieldy and not necessary to go through all the comments, but I did go to the effort of kind of classifying them, and to give you a flavor of what they were like, which is probably pretty meaningful.

Of all the comments, 50 percent were requirements or requests to update or add references. Actually, we had one case where someone wanted to delete a reference. We had

25 percent of the comments were to change the wording. The wording wasn't quite right or whatever. 26 percent of the comments were they wanted us to clarify certain points. It wasn't really clear, you know, there was some ambiguity what we were saying.

CHAIRMAN SHACK: Which comments are we talking about now, the earlier comments or the most recent comments?

DR. CAREW: These are the most -- yeah, these are the most recent comments, I guess. We had several -- round one and round two were first, and we resolved all those comments, or we thought we had resolved those. I think we resolved those comments, but industry asked us for this resolution of comments document, which had how we resolved each comment and what the basis of the resolution was. And we provided that to industry and then they commented on that document and also made new comments.

DR. SEALE: That's what this is.

DR. CAREW: And that is what this is. This is the last set of comments, which includes comments on the resolution of the previous comments, plus the new comments.

DR. TSOULFANIDIS: These were essentially received in '99.

DR. CAREW: These were all May '99 comments, right. And this is the sum, they went back and looked at all the resolution of our previous comments and the new comments, and made new comments which included that summary.

CHAIRMAN SHACK: These are May 2000 comments?

DR. CAREW: May 2000, right. But they encompass, basically, since in March -- yeah, March 2000, we provided all the old comments in the resolution, and we said, okay, now give us all your new comments, any comments you have. So these were all the outstanding comments, up to -- going back to day one.

MR. JONES: Let me interrupt you. The meeting that we had a year ago, September '99, we had made available the NUREG-6115 and the Draft Guide, and we had a meeting with industry. And that was the first time they had seen it for a while. So we actually solicited comments, we asked them to give us comments. And at that meeting they asked for the previous resolution of comments document, and so everything John has been talking about is for comments received this year.

DR. CAREW: So, okay, and some of these comments did address -- concern the earlier comments. Okay. And 26 percent were clarification where we had said things and they wanted them to be clarified. And then some of them asked for additional guidance, we didn't give them enough. They wanted to be told exactly how to do things, more detail on how to do things, and that was 9 percent. And there were some typographical errors. And about 15, 14 percent were actual technical issues.

Okay. Now, what I have done is I have gone through all those comments and picked out what -- well, before we do that, let me give you our approach to resolving the comments. First of all, all the comments were thoroughly, absolutely thoroughly evaluated for possible inclusion. We looked at every comment in detail.

And we then held the comments up to these criteria. We said for inclusion in the guide, we want this comment to be consistent with the scope and the purpose of the guide. It has got to be a technically valid comment, it has got to be technically valid. It has got to be a significant portion of the fluence determination, because we have gone into a lot of detail already and it just -- it had to be something significant.

It had to be consistent with presently accepted methods. If someone proposed something new, some new technique and it hadn't been reviewed or wasn't accepted, it wouldn't go in, because this is a guide that includes the methods that are acceptable to the NRC staff. So new, unaccepted methods would not be included. And the level of detail should not be overly prescriptive. There should be some wiggle room and some flexibility for the analyst to address his plan and treat items that may not be, you know, included, foreseen in the guide. So there has to be some flexibility in the guide.

Okay. So, now the comments -- this was the response, the response and the evaluation of the comments were based on a team consensus.

DR. TSOULFANIDIS: Who was the team?

DR. CAREW: Well, the team actually evolved. When we first started we had people, we had NIST, we had Jim Grundl and Dale McGary from NIST and a statistician from NIST, I forget his name. Do you know him, Graham? In any case, we had a statistician from NIST. Then we had, from Oak Ridge we had Dick Merker, Frank Kam, and Igor Renic. And I then I guess that is it.

Now, more recently, this has taken place over several years and some people have retired and the team has basically, the last set of comments, the team has been basically myself, Bill Jones and Lambros.

The resulting changes and additions to the guide have been incorporated into the latest version of the guide.

Okay. Let's see. Okay. All right. Now, what I have done is I have gone through all the comments, and I picked out -- I didn't want to bore you with all the comments, but I picked out what I thought were the most significant and important comments. Now, I would be very willing to answer any questions on any of the comments we haven't identified after I go through this. But let me first start by going through the comments I have selected and maybe I have got the ones you want to see.

First of all, there were some general comments made by NEI and the first one was that the final version of the NUREG report on benchmark problems should be released. Now, as Bill Jones just mentioned, that we have, at the September '99 meeting with industry, we released a draft copy of that report. And there were comments on that report in this set of comments which we are addressing. And I might add, there was no major change suggested to the guide, to the NUREG report.

But, in any case, we are working on this, finalizing the guide -- finalizing this report. Now, we expect to release this report in early calendar 2001.

The second comment was that NEI suggested that we have a round robin between industry contractors -- between NRC contractors and industry participants, doing calculations of a standard problem, the benchmark problem. Our response to that is that that is really outside the scope of the guide. The guide is intended to state what are accepted methods and describe them.

In addition, I mean the guide provides a highly detailed guidance on how to do calculations and measurements that are accepted and that can be input to Appendix G, 10 CFR 50.61, and the application of these methods appears in several of the references in the guide. In addition, the NUREG report presents several more applications of the guide's methods.

DR. KRESS: It seems like, though, if you had such a round robin, that it would be a good indicator of the potential variability of the results that you would get from user variability, and that might be of interest to NRC as something -- you know, it doesn't have to be put into the guide, but it sounds like it would be a good thing to do.

DR. CAREW: I am going to discuss that, I am going to discuss the NUREG report. And you will see, when we do those calculations, that if someone takes that problem and uses the methods in the guide, for example, the methods that are used for Palisades and Beaver Valley, whatever, uses the latest libraries and the current state of the art codes, they would get results that are very, very -- and we have done that. You will see --

DR. KRESS: I had in mind not using the benchmark problem, but to take a reactor core, and say this is what the core looks like.

DR. CAREW: Yeah.

DR. KRESS: And you go do it for this core and let everybody use the same core. But they have to prepare the right input and prepare everything and see what variation in results you get there.

DR. CAREW: Right. Well, now, let me just say this. That is how the benchmark problem is intended to be used and the licensees, when they evaluate their methods are intended -- they are supposed to go out and take that NUREG problem and do exactly what you said, take that core that is well defined, calculate it and see how they do, and submit that into NRR. And they are going to -- NRR will look at the results and say these look great and this will be the basis. And I will discuss in this more detail. But these look great, and that will be a large part, or a part of their licensee's approval of their methods.

To do the round robin, you would be doing exactly that and everyone would be doing it together. Well, actually, now that I think about it, that may not be such a good idea because it allows people to -- well, I guess it is good for the industry and everything.

But just let me say this, that there is -- we have just recently got a submittal where one of the licensees has done that. They have taken the problem and gone off and calculated and submitted that as part of their submittal. So that type of thing, the activity is going on. Maybe wait till the end and we will discuss it. After I go through the benchmark problems, we can talk about this, you can bring it up again.

MR. LOIS: John.

DR. CAREW: Okay. Lambros, you were going to say something.

MR. LOIS: Yes. To be more specific, yes, we did have and the other day, so the development of the methodology, we didn't have a round robin. And that was from Pacific Northwest in the laboratory where we did, the NRC funded a sizable dosimetry and calculational, consequently, calculational project.

At that time we did have a round robin calculation. In fact, we invited about 10 participants from national laboratories and the industry, and I do recall that we plotted the results and there was a factor of 3 top to bottom variation. And then we realized the enormity and the significance of the project, but, really, we did not know we could not reliably calculate fluences or even measure them to that effect.

That project, which lasted for several years, formed the background of what we have now. So such measurement and calculations have been part of the historical development of this guide.

DR. CAREW: And that experiment, that round robin was for the pool critical assembly benchmark experiment.

Okay. So these are the first two general comments that we had. And then I will go through some of the specific comments. The first comment is that the industry went back and looked at how we resolved the earlier comments and they made the observation that some of the responses to those earlier comments provided valuable insight and should be included in the guide. And went back and we agreed that some of these comments did actually provide valuable insights, but we also saw that some of them had already been -- we recognized that earlier had incorporated some of them already.

There were others that we saw and said, yes, these are good, and in the next version we have incorporated them. And then there were some that were outside the scope of the guide and we didn't think it would be appropriate to put them in. So we went back and looked at that and incorporated the ones that hadn't been incorporated already.

The next comment, there were several -- several commenters identified ASTM standards. For example, the ASTM standard which characterizes the neutron exposure of iron in terms of displacements per atom. We incorporated that standard. There was a standard on testing and benchmarking, we have incorporated that. The selection of dosimetry cross sections, and also there was one I left out here on the least squares adjustment methodology, that standard has also been incorporated. So the ASTM standards that were relevant, we have incorporated.

Let's see. The next comment was when the Monte

Carlo -- in the Monte Carlo analysis, you have to set up kind of a bin to record, for each neutron, the contribution to the dosimeter response. And the danger is the cross sections in these, for the dosimeters are thresholded -- have threshold cross sections, and if the bin is too wide, you won't get an accurate, because the fluence may be large down here in a region where the dosimeter cross section is small, and you won't do the integration correctly unless you have an appropriate bin structure.

So that was pointed out and that was a good comment, and we have incorporated that in doing the Monte Carlo calculation, you must make sure that the bin structure is fine enough to ensure an accurate integration over the cross section. So that has been included.

Another comment was that in the guide, as you might expect, that the Monte Carlo calculation, the major weakness in the Monte Carlo calculation is the statistics, the variance, and especially in these types of calculation where you have this strong attenuation, you have to make sure that -- and, typically, you can't do that. You can't do this calculation with Monte Carlo unless somehow you have a technique to increase -- reduce the variance, because if you start the neutrons off, you only get 1 per 1,000 hits the vessel and the statistics are very poor. So you have to some kind of a scheme which is going to reduce that variance. And there is variance schemes that people use.

And in any case, because of this, we recognize that we should put in some kind of criteria for people so that when they get a fluence estimate, they will know that it is reliable. So we put in five statistical criteria and the commenter noted that those criteria are really specific to MCNP. And so what we did is we suggested that these be set as a minimum set. And so we have changed the wording so that the criteria we have included there is a representative set, it is not a definite set. It is a representative set and not a minimum set, so that is how we have corrected that.

The next comment was -- this is a little bit tricky. When we do the benchmarking, we basically have three estimates of what the uncertainty is. We have an analytic estimate of what the uncertainty is, an estimate due to the plant dosimetry, and then we have an estimate based on comparisons to the simulator like the PCA. So there is three values. We have three independent estimates of what the uncertainty is and the guide was initially written so that we let the user assign a weighting to those based on what he thinks is the best number, and they asked us for more guidance.

Well, we recognize, first of all, that because the weighting of the analytic estimates depends on the details of the specific application, it is not really possible to specify a practical and generically valid prescription for determining the weights. It is really -- it would be unwieldy to put in the guide.

So what we have done is we have given an example, and we say that if you have a case where the source uncertainty is well known and the vessel diameter uncertainty is well known, the analytic uncertainty analysis will provide a good estimate of what the uncertainty would be and you can increase the weighting, say, from .3 to .5. And then, in addition, if you have -- if the measurement data, the dosimetry data is good, so, for example, you have 10 data points and they all have an accuracy of 5 percent, that estimate should be reliable and you can increase the weighting of that to, say, .3. And, consequently, the simulator weight would be .2.

So we have given an example that would indicate, you know, what you have to consider. You know, look at the uncertainty analysis and ask yourself how good is that. Look at the dosimetry, if you have a lot of good measurements that are really highly reliable, that is a good estimate and maybe the simulator is not so good.

So rather than try to have some kind of a generic prescription that would be unwieldy and wouldn't be appropriate for the guide, we have put this example in. I think that is about as far as we can go.

All right. Anyway, any comments?

[No response.]

DR. CAREW: The next comment was additional guidance on how the calculational benchmark should be used. We initially had -- we are going to use it to determine, to actually determine the uncertainty, make a quantitative estimate of the uncertainty. And the commenter suggests, why don't we make this into a go/no-go test? Well, we actually thought that was a pretty good idea and we have changed the guide. So the calculation of the NUREG benchmark problems will be basically a go/no-go test. You do the calculations. If they look at them, and they look reasonable, you are getting close agreement, you get a go. If they don't, you have to go back and look at your methods and revise -- either explain why you are getting large differences or revise your methods.

And we expect, as you will see, we expect the benchmark problems, since the problem is completely defined, very little source uncertainties or geometry uncertainties, you should get a very good, a very close agreement. And that is what we are -- okay.

The next comment was, while the guide provides guidance on what agreement we should expect when you compare integrated quantities -- integral quantities, there is no guidance on when you compare group-wise quantities, what type of agreement you should get. And that is true, we didn't give any guidance, and, therefore, we have removed that requirement. We no longer require them to compare group-wise quantities.

Another comment was we didn't define what a bias is or we didn't define bias or uncertainty in the guide. And so we have added a reference for the term bias.

The next comment was the level of detail required for benchmark analysis wasn't sufficient or we needed more data. And what we did is -- and let me point out that the benchmarks require a comparison to a simulator, which would be the pool critical assembly experiment, for example, the operating reactor dosimetry measurements or the NUREG report. I would just say first that we have already included several examples of simulator experiments, the PCA and the Venus. And in response to this comment, we have added some more references. So we have beefed up this area in response to this comment.

As far as the comparisons with dosimetry measurements, we just note that the calculations of plant dosimetry are required and are done routinely at all the plants. So these really -- there is plenty of information out there on how to do these calculations of the dosimetry measurements, and with the NUREG-6115, this includes examples, several examples. It includes the calculation and it includes how you do the calculation and the results. So we think that with respect to 6115, the benchmark problems, there is plenty of information out there on how to do benchmark calculations.

The next comment was that the simulator experiments do not provide sufficient detail to perform the benchmarks. This is similar to the previous question. As I said, we added references, additional references.

The next comments is that there are no results available that use the DG-1053 method and I would say that the NUREG-6115 report includes benchmarks results that have been determined used the methods of the Reg. Guide. There is also several of the benchmark experiments out there that are references, the H.B. Robinson experiment by Oak Ridge uses the methods of the Reg. Guide. And as Lambros mentioned a few minutes ago, several of the licensees, the Palisades and Beaver Valley calculations have been carried out using the methods of the guide.

So the methods of the guide are -- references of the application of the methods are fairly -- are available.

The next comment was that the benchmark problems were done with the BUGLE-93 library and the DORT code. Well, the calculations were done -- those libraries are a couple of years out of date. They have a new library now, BUGLE-96, and there is a new code called DOORS, which is actually a new version of DORT. And the comment was, well, we should do the NUREG problems using these new libraries and the new code.

And we agree that the codes, the nuclear data are being changed continuously, and we are presently reviewing this new library and this new code, and if we find that the differences have a significant effect on the application of this report and there is a need to revise NUREG-6115, that will be considered. And so we got in a time warp here, we can't keep up with the changes. But I really think, I am fairly confident that the changes are not that significant in those libraries and the code.

The next comment was additional guidance should be used in qualifying calculations and what constitutes an acceptable solution. Well, what we say here, we have added text to the guide that states basically that when you do the benchmark problem, if the differences between the benchmark problem calculation and the reference solution are substantially larger than what would be expected based on the difference in the methods approximation, the nuclear data, the calculation would be considered unacceptable.

In this case, if we get very, very large differences, when you do the benchmark problem, if you get very large differences, what do you do? Well, the calculation should be reviewed and the differences explained. And if the differences are due to an error in the calculation, the method should be revised. So that is how we address that.

CHAIRMAN SHACK: What is a very large difference?

DR. CAREW: Well, when you see -- who has the question? Okay. When we get to the benchmark problems, you will see. That is the next subject and you will see, we can discuss it at that point.

Okay. The next comment was, in addition to the solutions calculated with DORT and MCNP, there are other codes out there that we should use, namely, this is -- DORT is the Oak Ridge code, TWODANT is the Los Alamos code, and they are both discrete ordinates codes. This is an AEA Monte Carlo code, MCBEND, and this is -- I believe, I think that is what it is, yeah, it is AEA. And this is the Los Alamos Monte Carlo codes.

Now, all of these codes have been extensively -- they basically all use, you know, the Monte Carlo methods use very similar methods and so do the discrete ordinates, and they have all been well benchmarked and they have been around for a long time, so the code to code variations will be small. And as a matter of fact, you will see when we look at the benchmark problems comparison, they are very small. Even when we compare these two codes, the differences are, you know, are very, very -- are small.

So, we would expect, and I am very confident that if we use these other codes that the code to code variability would be much less than the uncertainties we are concerned about. We are concerned about uncertainties of 10 or 20 percent. The code to code variability would probably be of the order of a few percent. So that would be of interest, might be of some interest for code development or whatever, but looking at what we are looking at here, if somebody, if a licensee submitted, for example, a code with TWODANT, I don't think that, you know, it would be a major concern here. Okay. That was that question.

Okay. The next question was a request or a suggestion that if the purpose of the benchmark problem is to validate the implementation and the interfaces of the code, why not just provide the licensee the electronic input of the input data and the solution and they can just do it all electronically. But the point here is that the purpose of the benchmark problem is not to just validate the implementation of the code or the interfaces, it is also to validate the methods approximations and your set-up, and all your mesh and everything else. And if we provided the licensees both the input and the output, it would defeat that purpose, it would not be really a valid test of their methods. So we had to -- we couldn't, we didn't make any changes as a result of that comment. I think that was the comment, right. Yeah.

Okay. All right. Another comment was that the guide requires that the measurement, the laboratory measurement methodology be validated every few years, or periodically, and the comment was that we should quantify this statement every few years. Rather than saying every few years we should require that the laboratories validate their methodologies every two years or whatever.

And we have had -- it is amazing, we have had discussions of this issue for a long time, from day one basically. In any case, we have talked to other laboratories, we have talked to people that do the measurements, and the consensus overwhelmingly has been to leave the flexibility in there so that -- because there is a substantial variation from laboratory to laboratory as to the systems they use, the procedures, whatever, and we should allow them some flexibility so that they can set their own, you know, their own reasonable frequency of validation.

And then the last comment we thought was significant concerned the least squares approach. I don't know if you are familiar with this, but in this area, there are ways of -- you do a calculation and you do measurements. And after you do the measurements, you may want to go back and change your calculations. And there is basically two methods of doing that. You take your measurements, and you take your calculations, and you make ratios and you look at them to get a mean value and you determine that has a bias, and maybe if you really feel that that bias is really a solid number and reliable, and may help you, whatever, you would apply that as a multiplicative factor directly onto your calculation, and that is a direct deterministic method of doing that adjustment.

But, on the other hand, there are more sophisticated techniques that form the same ratios, measurements to calculation, but they take these into a set of ratios and they look at them statistically, and they build in different degrees of freedom into the calculations and measurements, and they take these degrees of freedom and they adjust them so they minimize the least squares difference.

So, anyway, some licensees use one approach and other licensees use this least squares adjustment approach. And some of the guidance in the guide I guess implied that we were excluding the least squares approach. So the comment was that the guidance conflicts with the least squares approach. Well, we have gone back into the guide and looked for any areas where the conflicts occurred and eliminated them. And this comment also suggested that we reference the ASTM standard on least squares adjustment, which we have done. So that is how we have addressed this comment.

DR. TSOULFANIDIS: John.

DR. CAREW: Yes.

DR. TSOULFANIDIS: Going back to 51, what if you say, instead of "every few years", "as deemed necessary", meaning if nothing new has developed in measurements and nothing has shown that measurements were done incorrectly, there is no need to do anything. But suppose a new development comes in, a better detector, a better technique, if you did the measurement today, you may have to revise it a month from now.

DR. CAREW: Yeah, I guess -- I hear what you are saying.

DR. TSOULFANIDIS: You may not have to do anything in 10 years, but you may -- Lambros.

MR. LOIS: This is Lambros Lois. There is such a provision in 50.61. It says that any significant difference in your calculations or measurements, you should report it.

DR. TSOULFANIDIS: I thought this refers to measurements only. Every few years, revise the measurement procedures or techniques.

MR. LOIS: Yes, but what I am saying is that there is an all inclusive provision in 50.61.

DR. TSOULFANIDIS: Okay.

CHAIRMAN SHACK: I wanted to suggest that this seems to me a good place for a break since we have finished with the NEI comments.

DR. SEALE: Yeah.

DR. CAREW: Good idea.

CHAIRMAN SHACK: Just take a break for 15 minutes. We will be back at 10:15.

[Recess.]

CHAIRMAN SHACK: I would like to resume our discussion.

DR. CAREW: Okay. The next comment was that -- this was by Ali Haghighat from Penn State, was that it wasn't clear that the Regulatory Guide methods, methodology was applicable to the BWR because of the fact that there is a substantial axial void distribution up the core axially, and also because of the fuel isotopics. And we have applied the methodology to a BWR benchmark problem in NUREG-6115, which I will discuss in a few minutes. So you will see that, in fact, we divide the core up into seven axial zones to accommodate that axial void behavior, and we know that this is adequate.

Let's see, the next comment from Ali was that the verification of the variance reduction method used in the fluence calculation is impractical, impossible. Now, as I mentioned before, because of the strong attenuation, when you do a Monte Carlo calculation, you have to somehow increase the statistics, pool your statistics, and what you do, one common technique is to split the neutron, so as the neutrons come in from region to region, that one neutron becomes five neutrons, becomes 10 neutrons, becomes 20 neutrons. So when you get to the vessel, instead of having that one neutron, you may have a hundred neutrons or a thousand neutrons, and that way, the variability is amongst the 1,000 neutrons, so the statistical fluctuations are much, much smaller. Instead of having one stock, you have a mutual fund which has a thousand stocks and the fluctuations are much, much less.

Anyway, so, that is how you get around the variance reduction problem. In all these variance reduction techniques, there is an approximation involved. And, as you might imagine, you don't get anything for nothing. If you reduce that variance, there is something you are cheating somehow and there is an approximation. And you must show that that approximation is valid, there is no error in that. And the guide recognizes and says, if you use variance reduction method, that is fine, but you must verify that you are not introducing a bias or there is not an error coming in. So we require it to be validated, and this comment says, well, it is impractical, impossible to validate it.

Well, when we ran the benchmark problems, we used a variance reduction technique. And what we do is we run two problems, one problem with the variance reduction and one problem without, and show that the results -- you know, it is just one case, you do that once, and show the variance reduction works. It is not valid -- it is valid, and then it is verified.

So, in response to this comment that it is not possible or practical, we have used it. We have actually verified this and carried this process out in the NUREG problems.

Yeah. Go ahead.

DR. TSOULFANIDIS: John, should you add to this the fact that you calculate fluxes using the Monte Carlo biasing techniques, et cetera, you use these fluxes to calculate dose rates, and you compare these calculated dose rates with the measured ones?

DR. CAREW: Right.

MR. LOIS: And that is another way to see how good your Monte Carlo results are.

DR. CAREW: Right. But I think that when you compare -- unfortunately, when you compare the measurement, you have to have a very good measurement. And, typically, the measurements, if you are going to try to validate your variance reduction technique, your splitting technique, for example, by comparing that to a measurement, you always have the problem, you know, the measurement, you introduce the measurement error and your measurement error may only be good to 20 percent. So you are really -- and, usually, when you run the Monte Carlo, you can run it down till you get statistics of like, you know, a few percent.

So, presumably, you would like to have a comparison that would see an error of 5 percent, and the measurement errors usually are larger than that and you may not be able to see -- you may not be able to get a credible or reliable validation of the variance reduction method against the measurement. So we would say the cleanest way to do it is take one calculation, use the variance reduction, and to take the same calculation with the same model, the same, you know, everything, everything exactly the same except you have no variance reduction. And this way you can see exactly the difference in those two calculations would be the effect of the variance reduction. And then it should be that both numbers agree to within the statistics.

DR. TSOULFANIDIS: Correct. But --

DR. CAREW: Okay. I missed your point, go ahead.

DR. TSOULFANIDIS: Not everybody will use the same variance technique. So if you did this for one specific problem, what you propose there is fine. But person B uses different variance techniques and this is not validated.

DR. CAREW: Okay. But the guide says the licensee, the analyst must validate his technique.

DR. TSOULFANIDIS: By doing this?

DR. CAREW: By doing this. So if vendor X comes in and he wants to use a variance reduction technique, whatever it is, it is may be splitting, it may be some other technique, but whatever it is, that is an approximation and he must validate it.

DR. TSOULFANIDIS: So for one case, they have to do analog Monte Carlo?

DR. CAREW: They must do a full Monte Carlo without the variance reduction, right. Some case that would do that. He has to pick out some case, maybe it is only a 1-D radial or a 1-D axial, it may be a simple calculation, but he has got to show that his, whatever trick he is using is valid.

It is just like using a discrete ordinate method, if you use a group structure of 47 groups, and you have got to show that that 47 group approximation is valid. So we consider the use of a variance reduction method, whatever it is, that is an approximation and there are certain assumptions built into that and they must be verified. And it is really important because these Monte Carlo calculations and the variance reduction techniques are complicated, they are subtle, you have to be very careful. And it is hard, you know, in any case, we have this --

DR. TSOULFANIDIS: Absolutely. They are called biasing techniques, but the trick is not to bias your result.

DR. CAREW: Not to bias it, right.

DR. SEALE: Thank God you have got the computers now that allow you to run these full Monte Carlos in a reasonable amount of time.

DR. CAREW: Right.

DR. SEALE: I mean the desktop machines do a remarkable job on some of these.

MR. LOIS: This is Lambros Lois again. But what Tsoulfanidis suggests would be ideal, would the best of all worlds. Unfortunately, the variation between -- on dosimetry measurements, between reactor to reactor, are quite significant, and even for the same capsule, we get significant variations between dosimeter to dosimeter and it would next to impossible to make sense out of that. So, therefore, you cannot use a measurement to, you know, verify the uncertainty for that.

CHAIRMAN SHACK: Just coming back to your comment one on the BWRs. Again, you know, I have shown an approximation is valid for one case. You know, how home-free does that get me?

DR. CAREW: Well, I mean if you look and ask yourself, you know, what is it about a BWR that would make these methods inapplicable, and the only question really is the void distribution.

CHAIRMAN SHACK: Does that mean every BWR is going to have to do, you know, five splits and then 10 splits and see if he gets a big difference?

DR. CAREW: No. I mean with the seven, dividing up the seven regions, the error, the error in the void fraction is less than the input void fraction. In other words, you calculate the void to be 30 percent, but, you know, the core calculation of the void fraction is 30 percent, that is plus or minus a couple of percent. Well, when you break it up into seven nodes on the periphery, the error in the void fraction is less than -- is of the order of the error in the input void fraction.

In addition, if you are the on ex-vessel wall, you are looking at, you know, you would be looking back at the vessel, but you might be looking at three different zones, okay, not just one zone. And each one would have their own error. You might be high here, low here. So it would integrate out and the error would be much smaller. So we believe seven is more than adequate for a treatment of the voids.

MR. HOPKINS: Bill Hopkins with Bechtel, but I am going to put on ANS-6 hat as the Chairman of the ANS-6 standard, and give some more historical data. In '85, EPRI funded SAIC to calculate what is a classic report on pressure vessel embrittlement with the state of the art then. And they did both the PWR and the BWR case. And they focused on this BWR void distribution as the key. But at the same time they also had the opportunity to go down and instrument Browns Ferry. That data is proprietary, but it exists. But it did benchmark the fact that even in '85 the methodology, which was the DOT at the time, with that -- I guess that was the Saylor cross sections that they were using, was sufficient to get you the responses.

It is something that is available through EPRI. But I always refer anybody wanting to try to calculate things like this for the first time, since 6115 isn't out, to go take a look at EPRI NP-152.

DR. CAREW: Thanks, Bill.

MR. LOIS: John, can I add one more comment? Since we are on the step, John, of this discussion, an additional difficulty with BWRs is the presence of the pumps and the risers. Unfortunately, because it is not cylindrical in nature, so it can be incorporated readily into two-dimensional calculation, they introduce a significant perturbation into the calculation and the prediction what is beyond that.

What makes that even more significant is that -- and rather unfortunate, is the GE practice to locate niobium and iron dosimeters right behind the pumps, with an enormous amount of iron. Of course, the spectral distortions were tremendous. And you get some measurements which most of the time you don't know what they mean anyway. So those are difficulties which have to be faced for the BWRs.

DR. CAREW: Okay. I have one more comment, and this was the comment from Bechtel Power, Bill Hopkins. And his comment was that he suggested the attached figure should be included in the guide to clarify the dependence of the fluence determination on fluence uncertainty. And we thought that was a good suggestion and we have incorporated that figure as Figure 4 in the guide.

Okay. Now, I would be willing to discuss any other comments, any specific comments, if anybody has any questions about any specific comments at this point.

[No response.]

DR. CAREW: Okay. All right. Now, I will go on to the pressure vessel fluence benchmark problem report, and some comments were raised earlier and, hopefully, this will address those comments. The NUREG report includes a set of pressure vessel fluence benchmark problems and solutions. The purpose of this report was to ensure the accurate fluence predictions and quantify uncertainty, and to standardize vessel fluence methods, and simply and streamline the licensing process. That was the purpose.

The way the benchmark problems would be applied is as follows, the methods are presented in great detail in the Regulatory Guide, and in the benchmark problem report, this provides the definitions, a complete definition and the reference solutions for these problems. The licensee would calculate the benchmark problems and provide the comparisons to the reference solutions to the NRC. And I would just like to say at this point, that, in fact, a licensee has just recently submitted the solutions to these problems to the NRC for approval as part of their submittal for the methods and provable.

And then, finally, the fluence methods would be accepted based in part on the agreement with the reference solutions. Okay. That is how the benchmark problem report would be applied, intended to be applied.

Now, the problem definition for the problem, we looked at four different types of cores. We looked at three PWR cores, a standard core and a low leakage fluence reduction core, and a partial link shield assembly fluence reduction core. And we have also looked at a BWR core.

The problem definition includes a description of the problem materials, geometry and pin-wise source. For each pin -- well, for each bundle, we provide the bundle power, the exposure, the burnup of that bundle to get the plutonium buildup, and we also provide the actual pin-wise power for the peripheral assemblies.

The problem is defined for typical operating geometry and materials, and the report includes a complete fluence analysis and execution of all the steps required for the RT PTS input.

I am now going to describe some of the problems. It is typical core-to-cavity dimensions, materials. A complete, detailed set of calculational input was provided. One of the things we were concerned about in defining these problems, we wanted to make sure that the problem included every single piece of data that was required, except maybe the speed of light and a few other things. But everything, everything was there, and we made a great effort to do that.

We have dosimeters on the standard wall capsule, on the vessel inner wall, and also in the cavity, and we have accelerated capsules. And we also provide the dosimeter ENDF-VI cross sections. So the user can use those cross sections and the cross sections will divide out of the comparisons.

Here is a picture of the actual problem. The red is the fuel, this is the core. We have got the baffle, the core barrel, the thermal shield. We have a capsule on the back of the inner wall of the thermal shield and a capsule on the vessel inner wall. We have a cavity capsule and a concrete shield. This describes the interface right here and we have the coordinate system. The coordinate system is important because when we give the pin-wise power in these peripheral assemblies, we need to know the orientation of the coordinate system. That is the PWR problem.

We also did a BWR, here is the BWR geometry. Again, here is the core region. The baffle, the shroud, the jet pumps and risers are included. The pressure vessel wall insulation and the concrete shield. As I mentioned before, we did, in the BWR, we have -- the axial treatment, a definition of the core is more complicated than the PWR. There is seven axial zones. And the steam separator and dryer regions, the core plate. Okay.

As I mentioned to you, the problem includes the complete geometry, the inner inlet thickness, the vessel clad thickness, all the geometry is included and all the temperatures and materials. And this problem has the advantage of you try to go and calculate a measurement, you know, a benchmark measurement, dosimetry in the capsule, you have the problem that you don't -- this problem doesn't have the uncertainty in the source. The source is completely specified. The vessel diameter, the geometry is completely specified. The material compositions will be completely specified. Everything is fixed. So the only thing should be different if two people calculate this problem is the implementation of the codes, the interfaces, and the approximations used in modeling the core. A representation of the jet pumps, how you represent those, all these different approximations that enter, they can be compared and validated very easily and cleanly in these comparisons.

This is the compositions for each isotope, here is the very fuel, the very fissionable isotopes 235, 239 and 240. So the whole problem is completely specified. And the solutions are tabulated based on standard fluence predictions. The flux is given, the flux above 1 MeV, about .1 MeV and DPA in the spectrum. We have also included in the report sensitivity calculations to various numerical schemes, you know, the various -- we did the calculation, we also provided a whole table of sensitivities. The selection of the quadrature S8 versus S16 and all the different assumptions, the numerical assumptions that we made, we provided sensitivities in the report. It is done with S8 P3. We have a synthesis, BULGE-93 cross sections, et cetera.

DR. SEALE: John, I have a quick question.

DR. CAREW: Yeah, go ahead. Yes.

DR. SEALE: The R theta diagram you showed what, a 45 degree sector?

DR. CAREW: Segment, right.

DR. SEALE: Do you then assumption reflection around those boundaries?

DR. CAREW: The guide states that if the core has octant symmetry, you can do the calculation in octant symmetry. And, typically, PWRs will have octant symmetry. But if the symmetry is broken, you may need to run a quarter core calculation.

DR. SEALE: I see. Okay.

DR. CAREW: Also, the layout of the jet pumps for BWRs is not always --

DR. SEALE: Scallop shield.

DR. CAREW: It is not always octant symmetric. So, depending upon the symmetry. Also, we say that if the peak fluence is in one octant, they could look at that octant. Or if a particular capsule may be in one octant, they may want to look at just that octant.

DR. SEALE: Yes. Yes.

DR. CAREW: But, of course, these are very expensive and time-consuming calculations, so you don't want to set up more of a jump than you really need. But you have to make sure that the system you are looking at has the proper symmetry, et cetera, to do that.

DR. SEALE: Sure.

CHAIRMAN SHACK: Just, in the nature, when you say these time-consuming calculations, what are we talking about on a modern computer?

DR. CAREW: Well, the discrete ordinate calculations are not that time-consuming, they may be five or 10 minutes, something like that maybe. But the Monte Carlo are really costly. They really take a lot of time. And that is the reason why we didn't have those in the guide initially, we thought that they would be too expensive and people wouldn't run them. And they might be an experimental tool, but not a design tool. But apparently there actually are -- they are creeping into the design tool, the design scheme, and as computers improve, so that is why we incorporate it. And those are very, very expensive, I mean they take a long time, days, weeks.

CHAIRMAN SHACK: Oh, okay. I mean we are talking that kind of time.

DR. CAREW: You are talking long, maybe even months.

DR. SEALE: There is one other comment here that I think is worth noting, and that is that the ENDF/B-VI cross sections mentioned here are different primarily in the way in which the details of the iron cross sections in the MeVish range, which is important here, are handled. And that work was actually financed by the NRC, as I recall, back in the late '80s and early '90s, essentially as a precursor to this evolution. And think when we hear people criticizing fundamental, so-called fundamental tasks and so forth, money spent on things that sound exotic sometimes, that it is instructive to recognize that here is some work which has immediate and serious impact on probably one of the most important questions facing the industry right now, namely, the credibility of the whole process of license extension. And so it is important to recognize that fundamentals count, too. This is a good example.

DR. CAREW: If I may say something, go one step further, that work actually resulted in identifying a substantial non-conservative in the fluence dose to the vessels, so I agree.

MR. LOIS: This is Lambros Lois again. Dr. Seale, thank you very much for recognizing that the need for this. I am the primary consumer of that information and the result of that research.

Going back to the symmetry that you mentioned, 45 degree, unfortunately, when some of the plants that tried to implement severe reduction in the leakage, and they tried to protect non-octal symmetry axial welds, they have to destroy the octal symmetry. In fact, they have one reactor that destroyed even the quarter symmetry and they are graphically about a half symmetry.

In that case, they can still go back and work on a 45 degree angle -- I mean segment, provided that the one that they work on is the one that contributes the most to the inside side of the pressure vessel.

DR. TSOULFANIDIS: I was going to say there is no true symmetry anyway. The question is how much asymmetry you are willing to accept.

MR. LOIS: Yes. Yes. Yes.

DR. SEALE: Right. It is a computational artifact.

MR. LOIS: Right. Right.

DR. TSOULFANIDIS: If you take the conservative quarter, yes.

MR. LOIS: Yes.

CHAIRMAN SHACK: Just coming back to, you know, your R theta meshes, I didn't notice any sensitivity studies where you varied the mesh geometries. I mean, you know, you picked a mesh and you did the calculation. Was that presumably based on previous studies?

DR. CAREW: Yeah, we have done, and you will see, the same way we do the comparisons with the MCNP, exactly how much that contributes. But we have done -- I have worked for Lambros over the years, and dating back -- well, over the years, these mesh were not just created here, we had a lot of experience, had done sensitivity calculations of what mesh was adequate. And, as a matter of fact, the guide specifies what an adequate mesh is, and that is based on previous -- the calculations that we have done that identifies the sensitivity to do that. Actually, it is -- what you have there, you have a Cartesian core and you have a polar coordinate system, an R theta coordinate system, and you have to map that peripheral geometry into little arcs. And the arc has got to be pretty small. Kind of like, if the boundary is like this, each arc has to cross it like this, like this, so you are going like this.

And that mesh, it turns out if you take enough mesh, and we do, and the industry does basically now, that that is a pretty small effect.

CHAIRMAN SHACK: What saves his bacon, too, is the fact that there is a lot of attenuation in the core. And so if you are sitting here looking at the core, it is the piece right in here that is closest to you and thinnest that dominates the dose out here. And this stuff gets kind of hidden in the self-attenuation in the core that is in front of it.

DR. CAREW: And, also, like if you make an approximation for this segment here, this segment will be low and this will be high, but these are very small segments, so at the inner wall, you are not just looking at that one small segment, you are looking at a whole integration of a summation of all those pieces.

So it gets to be, you know, it is about on the order of a percent or two. But, of course, mesh will be 2 percent, a fine mesh would be 1 percent, something of that order.

So, okay, let's see. The next slide is a slide showing the typical results. Here we have the fluence, the significant figures. This is a function of azimuth angle as you go around the vessel in a wall, and this is at the inner wall, quarter T, half T, three-quarter T and full thickness, and these allow a detailed comparison of the results.

Okay. Now, the next step was to discuss the Monte Carlo calculations, and this was, as we mentioned, this was a round two comment, which we have added as a result of the round two comment. And so what we have done is we have gone back, and after having done discrete ordinate calculations, we have gone back to those problems and redone them with Monte Carlo. As we know, Monte Carlo is an entirely different methodology. The geometry is represented by surfaces, each surface as far as the problem is explicitly represented in the problem.

We looked at a standard core, a partial link shield assembly core and BWR core, I though these were a fairly complete set. The Monte Carlo includes exact 3D geometry. We have a pin-wise -- the source is defined for each rod, it goes in explicitly, individually. And we have the same basic cross sections as the DORT calculation.

And I might add at this point we could have gone to BUGLE-96. BUGLE-96 had been on the street at this time, but we thought consistency is more important than the latest set of cross sections. We want to have the MCNP and the DORT, everything exactly the same and compare apples and apples.

So, let's see, and I might just say that we have used a region-wise importance variance reduction, or splitting, so the neutron is split. It is kind of interesting, each neutron that emerges from the core, by the time it hits the vessel, is a thousand neutrons, basically, to accommodate the factor a thousand attenuation.

We edited the flux above 1 MeV. Of course, with the Monte Carlo it cost. The lower the neutrons go, the lower you go, the much more expensive, and these calculations were very, you know, they are very, very time-consuming even on today's computers, especially if you make a mistake and have to redo it.

CHAIRMAN SHACK: This neutron splitting, is this what I think of as stratified sampling, that I am really taking samples from the neutron spectra that are the ones that get to the wall?

DR. CAREW: No, it is not the same.

CHAIRMAN SHACK: It is not the same thing.

DR. CAREW: The same is that you have a neutron that comes into one region and there is a boundary here, and as it enters that region, you say I am going to split that to four neutrons, say, for example. And you split it, it is now four neutrons. But what you do, and it is the same direction and orientation, whatever energy, but you now, to make it a fair game, you have got to reduce the weight in between those neutrons. If the weight of that initial neutron would start out to be 1, say, for example, now it is .73, and it is now four neutrons, you have got a sample, so the weights of these four neutrons carries the same amount of weight as the original one.

But the advantage is that when that neutron gets to the vessel inner wall, it is a thousand neutrons or, you know, 920 or whatever it is, and, as a result, the variability in your results, if one of those neutrons underwent a scattering in some region, it would only have a small -- or if one of those neutrons went straight through and hit the vessel directly, the vessel, the edit wouldn't jump up because it carries a small weight. Whereas, if it was one neutron and it went straight through, the tally on that edit would go way up, and the variance, when you took the mean value of that location, the mean value would be a certain number of neutrons, plus or minus 500 percent, or 100 percent, whatever. So that is how it works, it is not the same as stratified sampling.

Okay. So we have done these calculations. And as I mentioned, as we cut the problem off, you know, at 1 MeV because they are very expensive, and that was sufficient for the comparison. And interesting enough, we find that the agreement, after we ran enough histories, that the agreement was within 5 percent, roughly 5 percent. We were very happy with this result in view of the differences in all the methodologies. This 5 percent is due to the MCNP statistics which were about 4-1/2 percent, the DORT geometry representing the Cartesian geometry with this planar or radial coordinate system, polar coordinate system.

The DORT numerics, the fact that we have only a certain number, 50 angles, 48 angles to cover the sphere. And the fact that we are doing a synthesis. We do a radial calculation and an axial calculation. There is always a concern, you know, we can't do 3D, we are doing a synthesis calculation, how do you know that the radial and axial is separable? There is that issue. And this put that to bed.

So, anyway, now let me show you the results.

DR. TSOULFANIDIS: John.

DR. CAREW: Yes.

DR. TSOULFANIDIS: So the statistical uncertainties of the MCNP were less than 4.5?

DR. CAREW: Yeah, I think there were about 4 -- I think the statistics on the MCNP were maybe 4 percent, something of that order.

DR. TSOULFANIDIS: 4 percent. So the 5 percent is the difference just between the numbers obtained by MCNP and they don't --

DR. CAREW: Right. And I have figures, you will see.

DR. TSOULFANIDIS: Okay.

DR. CAREW: So it will be 5 percent, it is very good.

All right. The first case I have a comparison for the PWR, pressurized water reactor, and as a function of azimuth. As a function the angle, the flux above 1 MeV, MCNP and DORT, and you can see they track very well, they are close.

And the next calculation is a partial link shield assembly core, and I will just show you this core is a really tough test. And the core, the red is the fuel, but at the bottom 3-1/2 feet of the core, there is a weld simulated to be right over here, and the contribution to this weld comes from this 3-1/2 feet of fuel. And they cut out -- we have stainless steel rods in here. So we did this calculation both -- and this is a severe test of a synthesis also, trying to do a calculation like this.

So, in any case, here are the results. Let me find that. This is the MCNP and the DORT calculation, and, again, they agree very well.

DR. SEALE: That sort of confirms it is the outer skin closest that dominates the dose at a particular point.

DR. CAREW: Right. Yeah, we have done special cases where we have loaded in just the bottom outside row and we find that 85 percent of the signal is coming from --

CHAIRMAN SHACK: Now, would I find somewhat less agreement if I moved up axially till I, you know, say I hit that discontinuity? This is at the weld, is where you are really interested?

DR. CAREW: Right. I think probably -- I don't know. I don't know. Up here, you probably had very good agreement and it would degenerate somewhat as you get down here, I guess. But let's see. I don't know.

Actually, we do two calculations, we do a planar calculation and a planar calculation here. So, we are doing two calculations. I don't know, I really can't speculate if it would get better. We haven't done that calculation.

Okay. That is the PWR, and now this is the BWR. This is the -- yeah, okay. This is the result at the flux above 1 MeV at the downcomer and, actually, if you go back, if you remember, this peak here, which is a substantial peak, and this peak is due to the fact that the core -- this is the closest distance between the core and the vessel, and that is why there is a peak here. But, again, you can see the results were really -- I thought these results were excellent.

DR. SEALE: Where were the jet pumps in there?

DR. CAREW: Yeah, good question. The jet pumps are right over here, right here, and then there are some jet pumps over here. Let me think. But there is also, there is a location of close approach between the core and the vessel here. So this peak and this peak, and this peak here are due to the proximity to the core, distance to the core. I looked at that because I was wondering if I could see the jet pumps on this.

CHAIRMAN SHACK: Yeah, I mean you see less wiggle than you might expect from the geometry, I mean because there is an awful lot of jet pumps and risers, and yet you only see sort of, you know, two dips.

DR. CAREW: Right. Yeah, I didn't see -- I couldn't see the jet pumps on this, I really couldn't. But I know the jet pumps are worth about 13 percent, I know from previous calculations. So it is in here, but you don't see any abrupt, and that is probably because these are fast neutrons and I don't really see, you know, see the detail.

Actually, attenuation properties in steel and water are not that much different. If you go back to that figure on the beginning of the presentation, you will see that the fluence drops off rapidly in the water and it drops off fairly rapid in the steel, too, except at the interfaces, the spectral change that you get to see this wiggle.

DR. TSOULFANIDIS: What I find interesting is the ratio of the maximum to the minimum in the BWR is a factor of 5 almost, and in PWR is a factor of 2.

DR. CAREW: Right. And that is all dictated by the core peripheral geometry. We looked at a lot of these cores and as part of Shah Malik's work, we have been looking at a whole series of reactors and there we can see the effect of the core geometry. And it is interesting the dominant effect is the core geometry. You get some plants, if I recall, Oconee and Calvert Cliffs -- I think Oconee and Calvert Cliffs didn't have that much azimuthal variation, where Robinson had some severe, and it is all dictated by the distance between the core and the vessel inner wall, that determines the shape.

So we felt that this agreement is very good, and we feel that if somebody else goes and tries to calculate these problems, and they are going to be using the exact same problem, geometry, materials, source, exactly the same, where other comparisons, there is all kinds of variability. As you pointed out earlier, than when you construct a source, you have to go over cycles and go through all this calculation. That is all factored out of these comparisons.

So the only things that should affect these comparisons are two things, basically, the numerics, the numerical procedures in DORT, so long as you use DORT, for example, or MCNP. And those, the effect of the numerical procedures, you can see should be small. You have a synthesis here, and the selection of the mesh and everything else. The effect of the numerical procedure should be small, and if you use -- these are ENDF-VI cross sections, if you use ENDF-VI cross sections, even if is a BUGLE-96, I would anticipate even there, there is not going to be that much difference.

On the other hand, if you use BUGLE -- if you use ENDF-V or earlier cross sections, you would see a large variation. So if someone did a calculation of this benchmark problem with an earlier version of the cross sections, they would get a large difference and they would become aware that that difference is due to the cross sections.

DR. TSOULFANIDIS: Just a comment. In MCNP calculations, you can assign error bars.

DR. SEALE: Yes.

DR. TSOULFANIDIS: Without difficulty. It is much more difficult to assign error bars to the numerical deterministic calculations, but we know they are there.

DR. SEALE: You know, this is really interesting, it is almost like two guys getting lost in the woods 30 years ago, and one guy goes down a path where he does continuous slowing down, but he is limited on sample sizes he can use because of the number of neutrons he can use in the Monte Carlo. Well, the other guy does the discrete ordinate transport theory, but he has to use groups, and he is also limited because he doesn't -- he can't, in his discrete ordinates, represent the geometry with the kind of absolute faith that you can put into a Monte Carlo.

And suddenly these guys come out of the woods on the other end, and they got to the same place. And what it really indicates is a remarkable amount of very good judgment in which those compromises that were inherent to the two sets of methods were made in the evolution of those methods, so that, indeed, they turned out to be the right kinds of compromises when you got enough computing power to really hit the problem hard enough to get an answer.

There are not too many calculations where you have the effort put into them to demonstrate this kind of agreement where you have one or the other. So this has a lot more value than just in these particular calculations.

DR. CAREW: I agree with you, and I think it really confirms the two people ended up in the same place. I don't know who is bleeding more, but -- maybe it is the discrete ordinates guy. But there is a question who is smarter now.

DR. SEALE: Both of them are smart.

DR. CAREW: Yes. Okay. There is one more transparency. And I guess this is really -- I have to agree, really, it is kind of amazing that we could do this calculation. And this calculation, in a BWR, you probably recall that you have a BWR zirc alloy fuel channel with fuel roads inside and you a void fraction that varies from like 0 to 60 to 70 percent at the top of the core. And then you have, around that channel, you have a solid water region, a bypass region. And the question would be, do the neutrons care whether you take that -- when you do the calculation, do you mix the whole thing together and make it one composition, homogenize it, or does it care, do we have to go and represent those two regions separately, explicitly, as two different regions? Because you are pushing, basically, what you are doing is you are pushing water back and forward. The neutrons in the center of that assembly, some of those neutrons, if you push the water to the front, in the back into the bypass region, they are going to be seeing less water or more water, and you are wondering the importance of the neutrons and does it divide out or is it important.

So what we did is we did two calculations. We did one calculation, which was our first calculation, where we homogenized everything, and the second calculation we divided up and put an explicit water bypass region and the void region inside. And we did the calculations, in fact, our first calculation wasn't in such good agreement, we found a problem in the Monte Carlo. But, anyway, we looked closer and the calculations actually, I looked at these and I was kind of hoping I just could see the effect, but I can't even see the effect, I really can't. With all honesty, I really can't. Because I understand physically what should happen, but I can't see it. But this confirms that approximation, that you could do this in a homogenized way.

But, anyway, that is the end of my presentation. Are there any questions? I guess I will let Bill do the next presentation. I will just leave my stuff here.

MR. JONES: As I said, John has been involved in this effort all the time that it has been going on, and I think people are already getting a benefit from what has been done. There is already benefit, people are already using the NUREG and, as Lambros said, people are using the Draft Guide, so there is already benefit to that.

And I think the level of detail that John has gone into and that this effort has gone into, I think you have seen an indication of that. On my summary, which is the last sheet in your small package, John has talked about this, the level of detail in the guide, and he has just talked about the benchmark and the benefits that has and what it contributes.

When we talked about the history, we talked about it has been around since '93. We have had several public meetings, several rounds of comments. We have tried to really -- we have really been interested, everybody involved in this has been interested in making it better, and we have really tried to incorporate comments which we thought really helped the guide and improved it.

At this point the staff believes the guide is ready. The plan is to have the ACRS full committee on December 7th and we would like to publish the guide in early calendar 2001. We plant to publish the NUREG at the same time. That is really all I wanted to say in summary.

If there are any general questions or questions that we can answer? And, again, I want to thank you for your time.

CHAIRMAN SHACK: How fast do you think this is going to make a change? You know, if the guy is calculating away, is he going to suddenly switch? When is he going to get the heat to lean on him here?

MR. LOIS: This is Lambros Lois again. No, we don't expect any step function to arise because of the publication of the guide. As we pointed out earlier, all the licensees are aware of our requirements and they do account for them. As an example, we recently received a methodology and it practically has all of the -- it shows cognizance or awareness of all of the contents of the guide. So all we need to do, actually, what we are going to do now is to make it official, so to speak.

CHAIRMAN SHACK: We have sort of focused on what an impact might be on PTS. How about other kinds of embrittlement, would it have a bigger influence?

MR. LOIS: Absolutely. We had problems where we couldn't haven't gotten in the past help from the guide. The shroud problem, you are aware of that. Internals, core internals, pressure temperature curves, which are quite important, and so forth. So the guide will help quite a bit of application in a variety of areas.

CHAIRMAN SHACK: Thank you very much, Mr. Jones.

Any further questions?

DR. TSOULFANIDIS: We all know it would be nice to have in-vessel, ex-vessel measurements to compare the calculations with, because then you can bracket the result. And not all plants have ex-vessel measurements. Not all plants have ex-vessel measurements.

MR. LOIS: That is correct. However, in the context of Appendix H, we did give some guidance in the past that ex-vessel measurements would be acceptable as a substitute to satisfy the requirements for Appendix H. And those reactors that they really have an interest in pressure vessel, or have a problem, I should say, or close, they all have both, inside and outside measurements, because of their effort that they try to define the problem they had more closely, so the readily available thing to do is to go and get a copy of the measurements, and they have done that.

CHAIRMAN SHACK: I think we have a request from Mr. Warsham of Framatome to make some comments.

MR. WARSHAM: I am Tucker Warsham, I am representing Framatome Technologies, as well as the BWR Owners.

This guide really started to impact us in 1992, even though it officially wasn't out at that time. We brought the staff a review from a $2 million program on cavity dosimetry and we just completed it. And the staff informed us that the program was not sufficient without a reactor vessel calculational approach and a comparable calculational uncertainty methodology.

And, so, as we know, in 1993, February, there was the industry meeting, and then in September, the first Draft Regulatory Guide 1025. As far as we are concerned, we looked at what the fundamentals of the guide were. And the basic premise is that the current technology that the industry was using, which really included what we would call this unfolding or this adjustment technique to assess a measured fluence at dosimetry locations, and the fact that we then would proceed to extrapolate to the vessel the basic premise of the Draft Reg. Guide. Of course, this was not a consistent technology and particularly not consistent with respect to the way the PTS uncertainty analysis had been done at Oak Ridge, which was the fundamentals for the safety analysis of each type of B&W combustion and Westinghouse core.

So, in order to be consistent with the embrittlement, and particularly the PTS safety, again, what fundamentally the guide was saying, that if you were analyzing the vessel, that you should have a calculational uncertainty and something that could be used to define accuracy and precision of what the fluences would be at the vessel.

Okay. For several years, Framatome worked on the fundamentals of what the PTS safety analysis had actually been, the probabilistic work. We looked at the correlations that are the heart of Regulatory Guide 1.99, Rev. 2, and our objection was, of course, to prove that the staff was erroneous in their assessment that previous technology was not adequate.

Unfortunately, after spending a couple of years doing this assessment, we found that the staff was actually correct in their assessment. The old fluence technology was not consistent with the way PTS probabilistic analysis was doing, the uncertainties could not be shown to be consistent, and, therefore, additional work would be required.

Okay. The one thing that we found was the staff estimates in the Draft Reg. Guide what the cost would be to the industry. We found that this estimate was actually very much too low. Even John may have estimated, helped estimate that, as you can hear, if you are running a Monte Carlo code for a week or a month, and you are actually paying for a computer to do that, it is quite a bit more costly than what was originally put out in the guide.

What we would like to conclude by saying is, in consideration of these costs, what has the industry gained? And in truth, right now, if you say, what tangible benefits have we gained, we haven't gained any tangible benefits. We have gained benefits in terms of the plants inherently being more safe, but there is nothing we can report to and say, yes, we can extend the life of a plant one year or two years, or we can do something.

What we would like to suggest to the staff and to the ACRS, that there are now tangible benefits that should be considered. The first is we have been hammering on the uncertainties, as John showed. It is amazing, two totally different analyses, although done by his hand, so, I don't know, maybe there is some question, but two totally different analyses turned out to be right on top of each other, meaning that there is quite a bit of reduction in certainty from fundamental physics.

Okay. If there is such a reduction, one question that Lambros always has is, how are the material people interfacing with him, which is one of the issues of the whole draft guide to begin with. But if we have become more accurate, the inherent uncertainty in the PTS value in terms of delta temperature and in the pressure temperature curves for reactors, that uncertainty should be now considered to be reduced. And I am not saying that we know how, but I am suggesting that it is time for the fluence part of the Regulatory Commission and the materials part to get together and think about what can the industry gain and can we gain some margin reduction in the materials side because the fluence is now much more accurate?

And we also would like the ACRS and the staff to consider that now that we are predominantly doing calculations, 10 CFR 50, Appendix H, references an ASTM standard, I think it is 185, which requires considerable dosimetry ever time you are evaluating a reactor.

Now, if you conform to the guide, do you continue to need this much dosimetry, or is it now possible perhaps to reduce the total number of dosimeters down somewhat, maybe cut them in half?

There are two things that we would like to consider. So, basically, we have finished. If there are any questions you all have from those comments?

No, you know, Dr. Lois, I don't want any questions from you.

[Laughter.]

CHAIRMAN SHACK: There is a certain amount of discussion in the NEI comments, you know, that the Draft Guide still doesn't provide enough guidance, that it is going to be difficult to use. Have you looked at it and tried to use it? Do you have any feeling for whether you know what kind of rock you are supposed to bring?

MR. WARSHAM: From Framatome's perspective, we finished, we submitted a topical, we have argued with the staff, and the staff has accepted. So we feel very comfortable with the guide because we have gone through all the steps.

Before we went through all the steps, we had the same question as many others had associated with NEI, is there too much flexibility for the staff to say wrong rock after hundreds of thousands or millions of dollars had been spent? Go ahead.

DR. TSOULFANIDIS: When you say, should we reduce the number of dosimeters, what exactly do you mean? If we used 10 thresholds before, they use five now?

MR. WARSHAM: That is exactly what I am saying. Particularly in these two year cycles, what value is a nickel dosimeter that has a half-life of 87 days? Could we drop back, stick with some coppers and some uraniums or neptuniums, cut out some of the iron and nickel? Exactly. Rather than having four or five different types and three or four of each of those types, could we shut it down to a couple of types?

And before when we were highly relying on the measurements and using the measurements for this benchmark, I think the answer would have been no, but today, if you have been approved by the guide, if you are fundamentally now working on analyzing what the calculational technology, then can't you just use the measurements to continue to check that each time you do it, that you are okay, but you don't need quite so many measurements?

MR. LOIS: Can I answer that? I am not really -- the problem, I would rather define the problem than answer it. The question is legal as well as it is practical. In the practical sense, you are right, we now have sufficient information, have sufficiently developed the technology that we can do the same thing with fewer dosimeters.

However, the provisions of Appendix H have to be satisfied, a dosimeter has to be there. Now, that is a legal problem. On the other hand, the slowness with which the agency moves in changing the provisions of Appendix H, and Appendix G, for that matter, may have some wisdom in it, and that is, well, what if things.

A long time ago we thought the cross sections, we knew everything about it within 1 or 2 percent. Unfortunately, iron, as you know well, changed, and there are still some far flung questions out there remaining, kind of wandering around, such as their rate effect, some other things which we do not know the response to. And although for a time being it seems as if we are doing a little bit more to be certain what is going to happen in the future, particularly with life extension, we would rather do a little bit more rather than a little bit less, just in the case in the future something else shows up.

So, I agree with you that right now it seems as if with the improvement in technologies, the need is for less dosimetry. If we keep it there, keep it up, we may be better off in the future.

MR. WARSHAM: We would be happy to compromise and have the material people just take a couple of degrees off the delta T and we will kick the dosimetry in the core.

MR. LOIS: I don't speak for them, but, however, the methodologies that are right now in the works may actually effectively do that, what you are asking, namely, the introduction of probabilistic methods into the evaluation of the margin.

CHAIRMAN SHACK: Any other comments?

[No response.]

CHAIRMAN SHACK: I think we can bring the meeting to a close then. Are there any comments from the other committee members?

DR. KRESS: Are we going to have a letter on this?

CHAIRMAN SHACK: Yeah, we are going to have a letter on this.

DR. KRESS: Have you decided on what presentation you are going to have at the full meeting?

CHAIRMAN SHACK: Yes.

DR. TSOULFANIDIS: There was a comment in the beginning of the meeting about 1.99 and an approximate attenuation factor that is being used now. I assume if this is approved, then there is no need to use the approximate factor?

MR. JONES: I have a slide. This is an indication, you can see the red curve in the current attenuation factor in 1.99, Rev. 2. And this is part -- John mentioned that we have looked at several vessels as part of the probabilistic PTS work. Okay. So this is a comparison with a DORT calculation and the attenuation factor for a vessel. And they are very close for the first couple of inches, and the attenuation is conservative relative to the calculation. Is that the answer?

DR. TSOULFANIDIS: So you will keep using the conservative approach?

MR. JONES: Well, Shah is the PM for the probabilistic fraction mechanics work and he can address that issue.

DR. MALIK: This Shah Malik again. This probabilistic has to be done for the whole reactor vessel and we are using this approximate exponential decay at the moment. That is being further looked at in Reg. Guide 1.99, Rev. 3 revision that will be coming up soon also, how appropriate that term is. But in all likelihood, if it does not change, that is what we will be using, because those are like millions of calculations, it has to be on the fly in the computer to do those, calculating the probability of failure. And unless somebody builds up such a detailed model through the thickness of the vessel to go to the individual points, which the DORT calculation is showing up, that will make much more complication at the other end.

But the licensee does have the option, in their likelihood, they will save their plan and they can get a little bit of instructing, they could use that actual calculation. It is not going to stop them.

DR. SEALE: About 3-1/2 or 4 at nine inches is the difference between the two.

DR. TSOULFANIDIS: A factor of 4.

DR. SEALE: Yeah, 3-1/2 or 4.

DR. KRESS: Can't you just change your exponential function so it fits it better?

DR. MALIK: It will be then vessel-specific.

DR. KRESS: Oh, it is vessel-specific, okay.

DR. MALIK: It will then become vessel-specific.

DR. KRESS: Okay. You would have to run a lot of them.

CHAIRMAN SHACK: But how many vessels have you looked at? John says he is looking at a bunch.

DR. MALIK: He is looking at four of them right now.

CHAIRMAN SHACK: Four. Okay. That is a small sample.

DR. SEALE: Yeah.

CHAIRMAN SHACK: Do we see a consistent picture like that, though?

MR. JONES: I was just going to see a relatively consistent picture, yes.

DR. KRESS: So you could change it then.

MR. JONES: We are in that area of probabilistic fraction mechanics and that work is being done. We are exploring options, I guess.

DR. CHOKSHI: It is going, I think, you know, both the probabilistic PTS and Reg. Guide 1.99, we need to look at the whole thing.

CHAIRMAN SHACK: As I mentioned, I mean obviously you do know more about the uncertainty than you did when you wrote 1.99, Rev. 2. I mean it just has to be factored in.

DR. CHOKSHI: Because some of the other comments from Framatome, you know, we need to look at the whole thing and see what are the implications.

CHAIRMAN SHACK: I guess maybe the first thing is, what do we want presented at the full committee? How much time do we have?

MR. DUDLEY: We have an hour-and-a-half.

DR. SEALE: Working backwards, I would think it would be worthwhile to see the comparison between the MCNP and transport calculations for those four cases. I would imagine that you could probably sample particularly the EPRI or the NEI comments.

DR. KRESS: I would eliminate most of those because --

DR. SEALE: Yeah, but just to indicate the nature of the more relevant ones.

DR. KRESS: I would just show that pie chart and indicate maybe the general nature.

DR. SEALE: Yes. Yes. Then I think you would probably go through the front part of it pretty quickly.

CHAIRMAN SHACK: Okay. That maybe seems to me a reasonable thing to do, to basically just, you know, very abbreviate the discussion of the comments, but to keep the rest.

DR. SEALE: The pie chart is a lot of the thrust really.

MR. DUDLEY: How much detail do you need on a NUREG?

CHAIRMAN SHACK: Well, Bob was saying he sort of liked that detail.

DR. SEALE: Well, I think it is the phase of maturity that I think is important to understand when you are making these kinds of questions. And I think the comments from Framatome suggest that at some point down the road, it may be appropriate to examine some of these issues.

DR. KRESS: It seems like a general principle, if you reduce the uncertainties, you are liable to get some benefit.

DR. SEALE: Yeah. And it is worthwhile for the committee to know that, you know, the rolling tide of understanding has gotten to this point, and so maybe it is going to be time to ask some of these questions again.

DR. TSOULFANIDIS: That is not part of this NUREG.

DR. SEALE: No, I am not saying that.

DR. KRESS: That is something else.

DR. SEALE: But it brings the committee up to date on the status of that calculation.

MR. JONES: So what I am hearing is much of what John presented, you would like to hear in abbreviated form, and you would like to see the pie chart. Do you want any comments at all presented by John, or how do you want to handle that, any of the industry -- any of the public comments?

DR. KRESS: I think the full committee can read most of those.

MR. JONES: Okay.

CHAIRMAN SHACK: You have got that nice table.

DR. KRESS: You have got a nice table and it is really easy to follow.

MR. JONES: Okay.

CHAIRMAN SHACK: One by one, and I think that is -- you know, the one substantive comment is the one on the BWR and, you know, rather than the sort of ex cathedra statement that it works, you know, you might point that out when you get to the NUREG, that you have got the calculations.

DR. KRESS: Yeah, I think that be worthwhile.

CHAIRMAN SHACK: Because some of the others are more -- you know, yes, they are important, but I think those are readable.

DR. KRESS: I would like to see a little more of the technical basis behind your weighting factors for the three uncertainties. Those look a little arbitrary to me. Maybe that is all there is to them, but it left me a little cold.

MR. JONES: Well, what I heard during the break, I think part of what you see there is some of us have toiled in the nuclear analysis part of the industry for a long time, and what we were trying to do is say, what is a reasonable way to group these sources of uncertainty and weight them properly? Maybe that is just what is needed. But those of us toil in that nuclear, you know that a lot of that is experiential.

DR. KRESS: I understand, that is probably what it is.

MR. JONES: Right. So we will address that and try to do a good job with it.

DR. KRESS: Okay. I am pretty sure the question will come up, knowing the committee.

CHAIRMAN SHACK: Well, not if they don't discuss that comment, that is one way to get around it.

[Laughter.]

DR. KRESS: You're right, but George will find it.

DR. SEALE: We might may make him bring it up anyway.

[Laughter.]

CHAIRMAN SHACK: That is enough then to give you a notion of what to bring for the hour-and-a-half.

MR. JONES: Okay.

DR. SEALE: Nick, was there anything else?

DR. TSOULFANIDIS: I was going to ask John something. The temperature of the moderator is important, of course, and it is not constant, even in the PWR, as you go up. Has this been addressed? It is lower at the bottom or at the top? The average, I recall is, what, .7 water density in the PWR, right? But does this produce an effect, did anybody look at that?

DR. CAREW: The guide raises these issues and states that you must account for the temperature, and we have looked at that. We looked at the temperature of the coolant, it enters several places. It enters in the downcomer temperature, and that is typically, that is an uncertainty that we have looked at in the uncertainty analysis. And, typically, when the temperature, the inlet temperature is used, the uncertainty in the inlet temperature contributes about 2 percent at the most to the uncertainty in the fluence, so it gets lost compared to the other larger uncertainties.

The temperature in the bypass region also is known and also the uncertainty -- well, let me go back a step. In an operating plant, the uncertainty due to the measurement uncertainty in the inlet temperature, it contributes about 1, probably 1 percent, 1-1/2 percent to the fluence uncertainty. Then there is a question, in each one of those regions, you have a distinct temperature, and, again, the absolute temperature -- across the core, there is maybe a 60 degree temperature rise across the core, in the center of the core, and the peripheral bundles where it counts is maybe a 30 degree rise. So the uncertainty in that temperature is much smaller, or the effect of that is much smaller than the uncertainty in the downcomer where you have a much larger thickness of water and you have a larger -- you have a significant uncertainty.

So the major contributor to those temperatures turns out to be relatively small, and it is swamped by the uncertainty in the source which typically could be 10 percent. So you are comparing a 2 percent, a 1 percent uncertainty to an uncertainty in the source which is 10 percent, you won't even see it.

That doesn't account for the uncertainties in the problem, the nuclear data uncertainties. Well, let me go back a step. The overall uncertainty in a good calculation nowadays may be of the order of like 15 percent. So you are going to add on or subtract a 1 or 2 percent uncertainty, you will never see it. So, in practice, the temperatures really are not that important, but they are a consideration and we have looked at them.

DR. TSOULFANIDIS: One other source of uncertainty is if you take the pins in one assembly, they don't all have the same burnup. Therefore, if you look at them as a source of neutrons, they don't produce the same number of numbers. And this critical, as we know, for the last row of assemblies at the periphery of the core.

In the Monte Carlo calculation, you pointed out that you looked at the pins individually, if I understood you correctly, and, therefore, this neutron source was introduced into the Monte Carlo calculation based on pin by pin. I assume this was based on isotopics calculations.

DR. CAREW: Right.

DR. TSOULFANIDIS: How was this done with the deterministic code?

DR. CAREW: Okay. In the deterministic DORT calculation, we also included the exact same source, the exact same pin powers and the exact same exposure. So the same data went to both calculations. The only difference was that in the DORT calculation, that information had to be smeared and mapped onto an R theta geometry which distorted it. But we have a code that does that and the mesh on the periphery of those peripheral bundles is pretty fine. So we get a pretty detailed, I mean if we have a 15 by 15 bundle on the core, we don't have a mesh of 15 by 15 in those peripheral bundles, but we have probably close to 200 mesh points in that, so it gets a pretty good representation.

DR. KRESS: I was fascinated by the fact that you could use a homogeneous calculation and get the same answers as a heterogeneous one. I don't suppose that is very surprising. But what are the implications of that? Does that help you make the calculations easier or does it help somebody do it a lot faster, or does that help any?

DR. CAREW: Yeah, I was amazed also, kind of disappointed in a way. But it may be due to -- we are looking at fast neutrons, I don't see that detail they are going so fast. They have scattering events that occur like every six inches or something like that.

DR. KRESS: It is the scattering that makes it different.

DR. CAREW: So they don't see that detail. But it makes a big, a very, very big simplification. It means that in the DORT calculation, where you really can't represent it explicitly, that DORT calculation does a good job, and that is what we see.

DR. KRESS: That explains why the DORT does a good job.

DR. CAREW: Exactly.

DR. KRESS: That is the implication of that.

DR. CAREW: Right. Yes. I thought we might give it streaming, some kind of streaming effect, but it didn't occur. We don't have it.

DR. KRESS: You might want to bring that detail out a little more when you show that particular slide.

DR. CAREW: Okay.

CHAIRMAN SHACK: Is your smearing code described in a NUREG, I mean is that -- that would seem like an important input to these kinds of calculations, just how that smearing is done.

DR. CAREW: Well, you mean the mapping code?

CHAIRMAN SHACK: Yeah.

DR. CAREW: There are several different mapping codes out there. We have a code that is referenced in the Reg. Guide and there are different codes that do that same job.

CHAIRMAN SHACK: Have you looked at the sensitivity of the calculation to those mapping codes?

DR. CAREW: Well, let me go back a step, give you some perspective. The effect of all that detail on the periphery is worth about maybe 7 or 8 percent to the vessel fluence. It is not an enormous effect, but it goes -- I mean it helps, it reduces the fluence, so it is worth going after. So we are talking about only, you know, it is a 7 or

8 percent effect. So you are not going to -- we have a requirement in the Reg. Guide that the peripheral bundle should be represented in such a way that the area of the peripheral bundle is represented in the R theta mesh, is good to half a percent. So we require an accurate modeling of that peripheral boundary.

And I don't know that you have to put in each pin explicitly. You probably could get by with a coarser representation, and it is probably not really not necessary probably. If the neutrons aren't seeing a difference between the void fraction inside or outside the bundle, they are probably not going to see whether it is the second or third row in pin.

CHAIRMAN SHACK: If there are no further questions, I believe we can bring the subcommittee meeting to an end. It was a very good presentation, I enjoyed it very much.

[Whereupon, at 11:38 a.m., the meeting concluded.]

REPORTER'S CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

NAME OF PROCEEDING: MATERIALS & METALLURGY SUBCOMMITTEE MEETING (ACRS)

CASE NO:

PLACE OF PROCEEDING: Rockville, Maryland

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Jon Hundley
Official Reporter
Ann Riley & Associates, Ltd.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MATERIALS AND METALLURGY SUBCOMMITTEE
CALCULATION OF NEUTRON FLUENCE DG-1053
TH., NOVEMBER 16, 2000
ROCKVILLE, MARYLAND

ROOM T2-B3

- PROPOSED AGENDA -

	TOPIC	**PRESENTER**	**TIME**
I.	Opening Remarks	W. Shack, ACRS	8:30-8:35 a.m.
II.	Introductory Remarks	N. Chokshi, RES	8:35-8:45 a.m.
III.	Overview and Status of DG-1053	J. Carew, BNL	8:45-9:45 a.m.
	- BREAK -		9:45-10:00 a.m.
IV.	Review of Industry Comments	J. Carew, BNL	10:00-11:00 a.m.
V.	Review of NUREG/CR-6115, "Pressure Vessel Fluence Calculation Benchmark Problems and Solutions"	J. Carew, BNL	11:00-11:30 a.m.
VI.	Discussion	W. Shack, ACRS	11:30-12:00 noon
VII.	Adjournment	W. Shack, ACRS	12:00 noon

NOTE:

Presentation time should not exceed 50 percent of the total time allotted for specific item. The remaining 50 percent of the time is reserved for discussion.

Number of copies of the presentation materials to be provided to the ACRS - 25.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE MATERIALS AND METALLURGY SUBCOMMITTEE
11545 ROCKVILLE PIKE, ROOM T-2B3
ROCKVILLE, MARYLAND
NOVEMBER 16, 2000

The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Materials and Metallurgy . I am Dr. William Shack, Chairman of the Subcommittee.

ACRS Members in attendance are Thomas Kress and Robert Seale.
Also in attendance is ACRS Consultant Nicholas Tsoulfanidis.

The purpose of this meeting is for the Subcommittee to hear presentations by the staff concerning the proposed final regulatory guide on calculational and dosimetry methods for determining pressure vessel neutron fluence. The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee. Mr. Noel Dudley is the Cognizant ACRS Staff Engineer for this meeting.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the *Federal Register* on October 25, 2000.

A transcript of this meeting is being kept, and will be made available as stated in the Federal Register Notice. It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

We have received no written comments. A representative of Framatone requested the opportunity to make a statement at the end of the meeting.

The ACRS examined draft regulatory guide DG-1025, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," in 1993 and requested the opportunity to review the proposed final version after public comments were reconciled. Subsequently, DG-1025 evolved into DG-1053. The staff briefed this Subcommittee on the status of DG-1053 during its April 15-16, 1997 meeting. More recently, DG-1053 evolved into the proposed final regulatory guide we are reviewing today. During this evolutionary process stakeholders had opportunities to provide comments on the different versions of the regulatory guide.

Today we will hear a presentations regarding the proposed final regulatory guide. We will now proceed with the meeting and I call upon Dr. Nilesh Chokshi, Chief of the Materials Engineering Branch, to begin.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS MATERIALS AND METALLURGY SUBCOMMITTEE

CALCULATION OF NEUTRON FLUENCE REGULATORY GUIDE

Dr. Nilesh Chokshi, Chief
Materials Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research

301-415-6013

Purpose of Presentation

- To Discuss Final Version of the Regulatory Guide
- To Discuss Disposition of Public Comments
- To Seek ACRS Approval to Issue the Final Regulatory Guide

Need for Regulatory Guide

- Provide Standardized Methods and Procedures for Fluence Calculations and Use of Vessel Dosimetry

- Wide Variety of Application of Existing Methods for Determining Fast Neutron Flux

- Comply with Regulations on Reactor Pressure Vessel Integrity

Status of Regulatory Guide

- Initial Efforts Started in 93
  - Publication of 2 Drafts
  - 3 Rounds of Public Comments
  - 3 Public Meetings
  - 5/00 - Latest Round of Comments Received
- 11/00 -Appropriate Comments Incorporated
- Plan to Publish Early 2001

Presentation Outline

- Overview of the Guide — William Jones, NRC
- Guide Technical Details — Dr. John Carew, BNL
- Summary and Schedule — William Jones, NRC

U.S. NRC Office of Nuclear Regulatory Research
Division of Engineering Technology
Materials Engineering Branch

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MATERIALS AND METALLURGY SUBCOMMITTEE

CALCULATION OF NEUTRON FLUENCE
REGULATORY GUIDE

William Jones
Materials Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research

301-415-7558

U.S. NRC Office of Nuclear
Regulatory Research
Division of Engineering Technology
Materials Engineering Branch

Introduction

- Objectives of Regulatory Guide
- Contents of Regulatory Guide

OBJECTIVES OF REGULATORY GUIDE

PROVIDE:

- METHODS FOR FLUENCE CALCULATION AND USE OF DOSIMETRY FOR DETERMINING RPV NEUTRON FLUENCE THAT SATISFY REGULATIONS.
- DESCRIPTION OF FLUENCE CALCULATION METHODS
- USE OF DOSIMETRY MEASUREMENTS FOR VALIDATION OF CALCULATIONS
- PROCEDURES FOR QUALIFICATION OF CALCULATIONS & DETERMINATION OF UNCERTAINTY
- MEASUREMENT PROCEDURES

CONTENTS SUMMARY

- FLUENCE CALCULATION METHODS
  - Input Data
    - Materials & Geometry
    - Cross-Sections
    - Neutron Source
  - Fluence Calculation
  - Qualification & Uncertainty

- DOSIMETRY
  - Procedures
  - Dosimeters
  - Measurement Uncertainties
  - Validation
  - Fluence Estimates Based on Measured Data

CONTENTS SUMMARY

(CONTINUED)

- REPORTING
  - Methods
  - Calculation vs Measurement

- IMPLEMENTATION

Summary

- Detailed Information on Fluence Calculation and Measurement Methods
- Benchmark Calculations in NUREG/CR-6115
- Extensive Review and Substantial Public Participation
- Believe Regulatory Guide is Ready for Final Publication
- Full ACRS Committee Meeting Planned for 12/7/00
- Publish Early 2001

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MATERIALS AND METALLURGY SUBCOMMITTEE
CALCULATION OF NEUTRON FLUENCE DG-1053

Presented by

John Carew

Energy and Nuclear Technology Division

Department of Energy Science and Technology

Brookhaven National Laboratory

November 16, 2000

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MATERIALS AND METALLURGY SUBCOMMITTEE
CALCULATION OF NEUTRON FLUENCE DG-1053

Presented by

John Carew

Energy and Nuclear Technology Division

Department of Energy Science and Technology

Brookhaven National Laboratory

November 16, 2000

Background

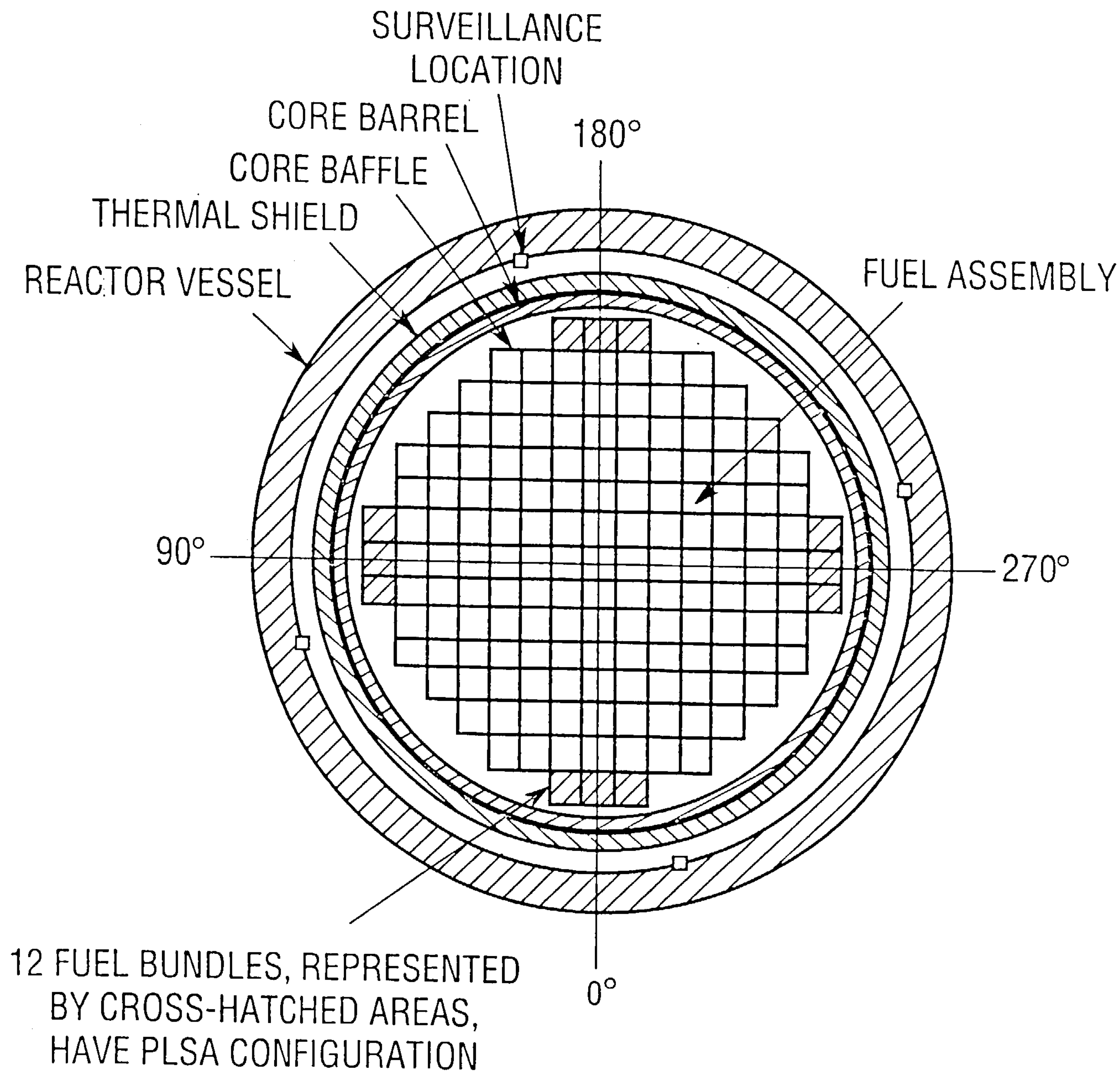
- Reactor Pressure Vessel Fluence is Required for Determination of Vessel Embrittlement and Lifetime

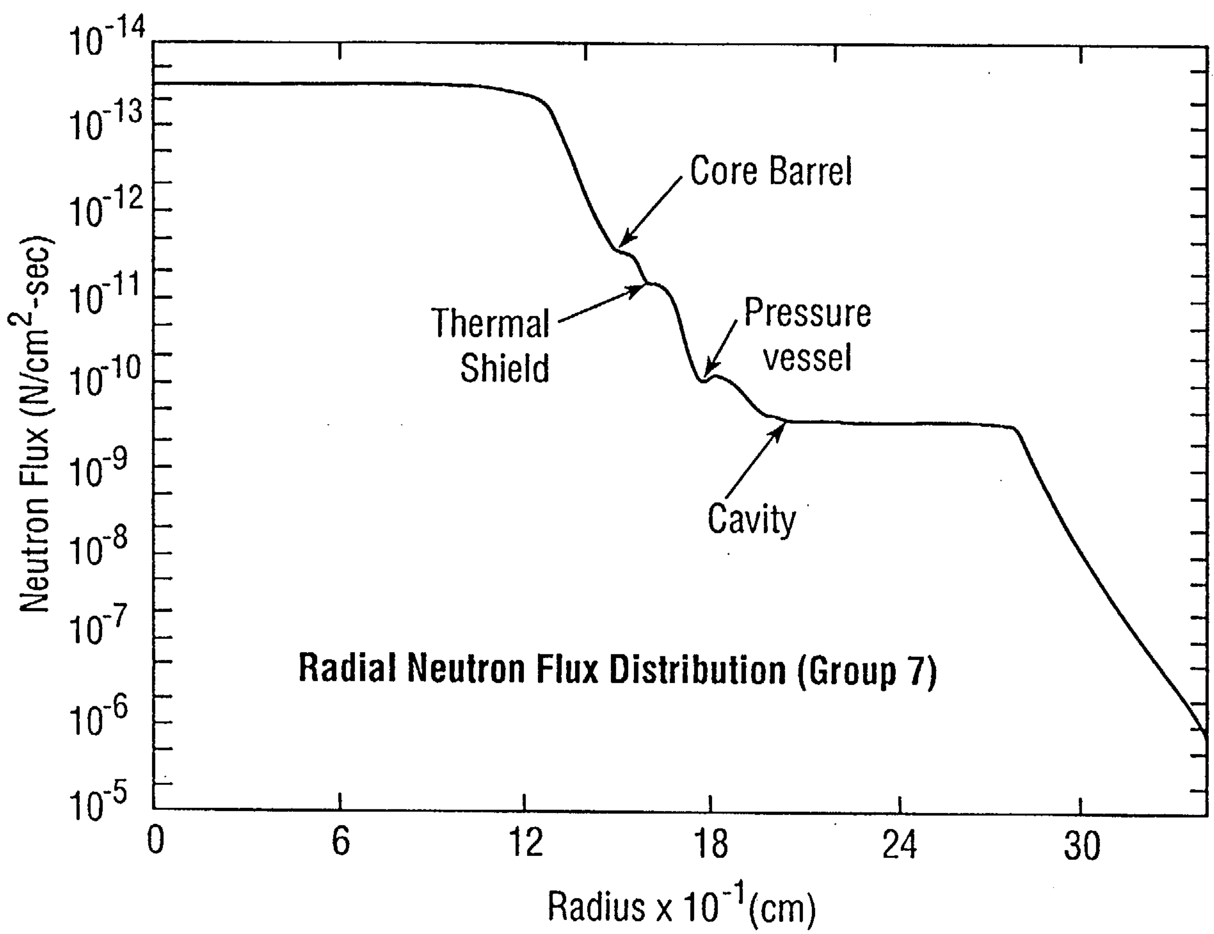
- Vessel Fluence is used to Determine the Adjusted Reference Temperature for the Nil-Ductility Transition RT_{NDT}

- The "PTS Rule", 10 CFR PART 50.61, Requires the Determination of the Fluence for RT_{PTS}

Background

- Neutron Fluence Undergoes Several Decades of Attenuation Between the Core and Vessel
- Fluence Calculation is Therefore Sensitive to
  - Material and Geometry Representation of the Core and Vessel Internals
  - Space/Energy Neutron Source
  - Transport Calculation Numerical Schemes
- Detailed Multigroup/Multidimensional Analysis is Required for an Accurate Fluence Estimate


SURVEILLANCE
LOCATION
CORE BARREL
180°
CORE BAFFLE
THERMAL SHIELD
REACTOR VESSEL
FUEL ASSEMBLY
90°
270°
12 FUEL BUNDLES, REPRESENTED
BY CROSS-HATCHED AREAS,
HAVE PLSA CONFIGURATION
0°



Radial Neutron Flux Distribution (Group 7)
Core Barrel
Thermal Shield
Pressure vessel
Cavity
10-14
10-13
10-12
10-11
10-10
10-9
10-8
10-7
10-6
10-5
Neutron Flux (N/cm2-sec)
0
6
12
18
24
30
Radius x 10-1(cm)

Background

- Wide Range of Fluence Methods are used: Cross Section Sets, Physics Approximations (Source and Axial Treatment) and Codes

- Limited Number and Uncertainty of Capsule Benchmark Data

- For Certain Vessels Limited EOL Margin to RT_{PTS} Limits

Presentation Overview

- Review Regulatory Guide DG-1053
- Resolution of Industry Comments on DG-1053
- PWR and BWR Pressure Vessel Benchmark Problems - NUREG/CR-6115

Regulatory Guide DG-1053

- Developed
  - For - Materials Engineering Branch
    Division of Engineering Technology
    Office of Nuclear Regulatory Research
  - By - Brookhaven National Laboratory
    - National Institute of Standards and Technology
    - Oak Ridge National Laboratory

Summary of Regulatory Guide DG-1053

- Purpose
  - Document calculation and measurement methods for determining pressure vessel fluence that are acceptable to NRC

- Scope
  - Vessel fluence determination for input to CRF 50.61 RT_{PTS}, input to Regulatory Guide 1.99 and Appendix-G

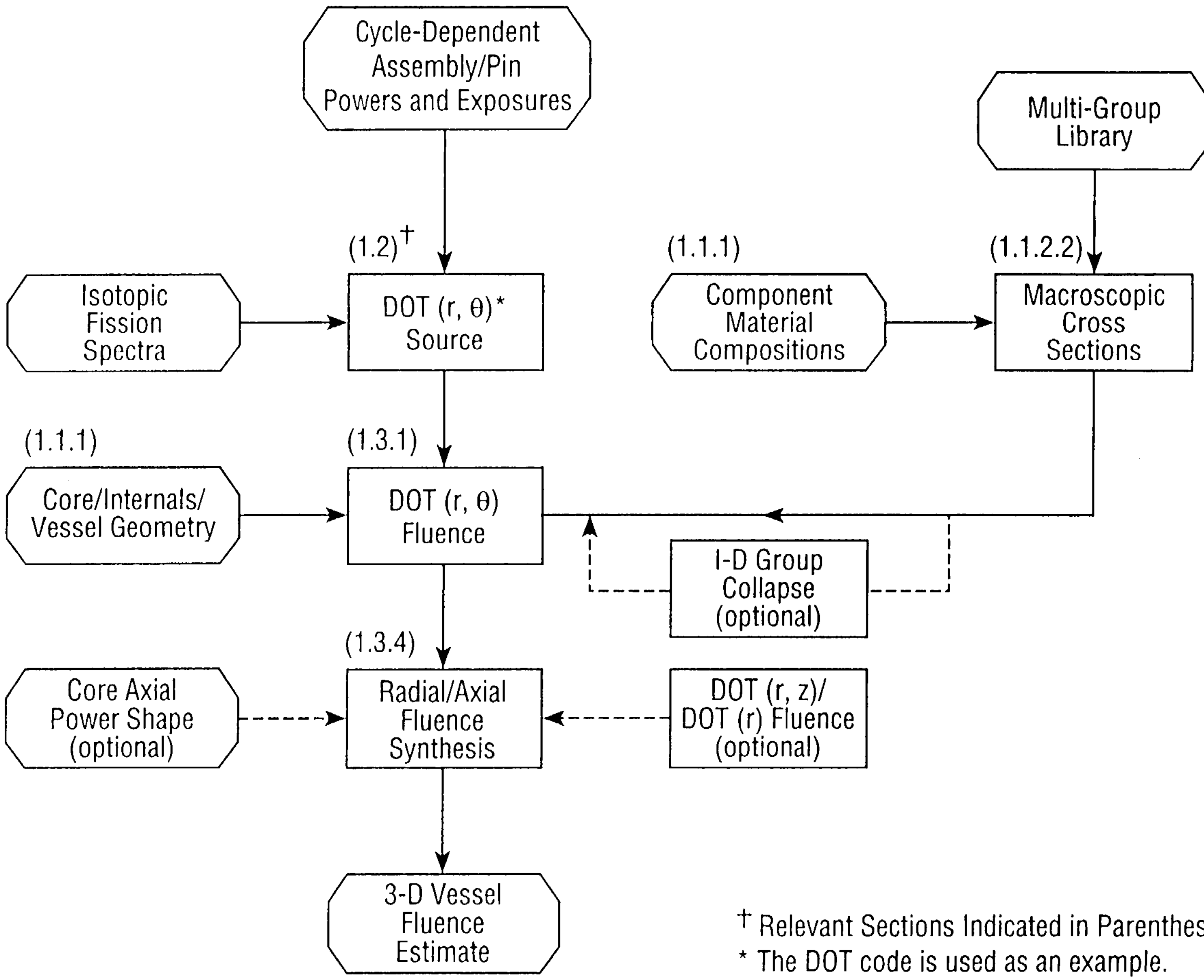
Summary of Regulatory Guide DG-1053

- Includes
  - Detailed description of fluence calculation and measurement methods
  - Procedures for qualification of calculations and measurements
  - Table of specific modeling, dosimetry,qualification and reporting requirements
  - Requires calculation of NUREG/CR-6115 pressure vessel fluence benchmark problems for methods qualification

Summary of Regulatory Guide DG-1053

- **Primary Calculational Tasks**
  - Determination of Geometrical and Material Composition Data
  - Determination of the Core Neutron Source
  - Transport Theory Calculation of the Neutron Flux from Core to Vessel and Cavity

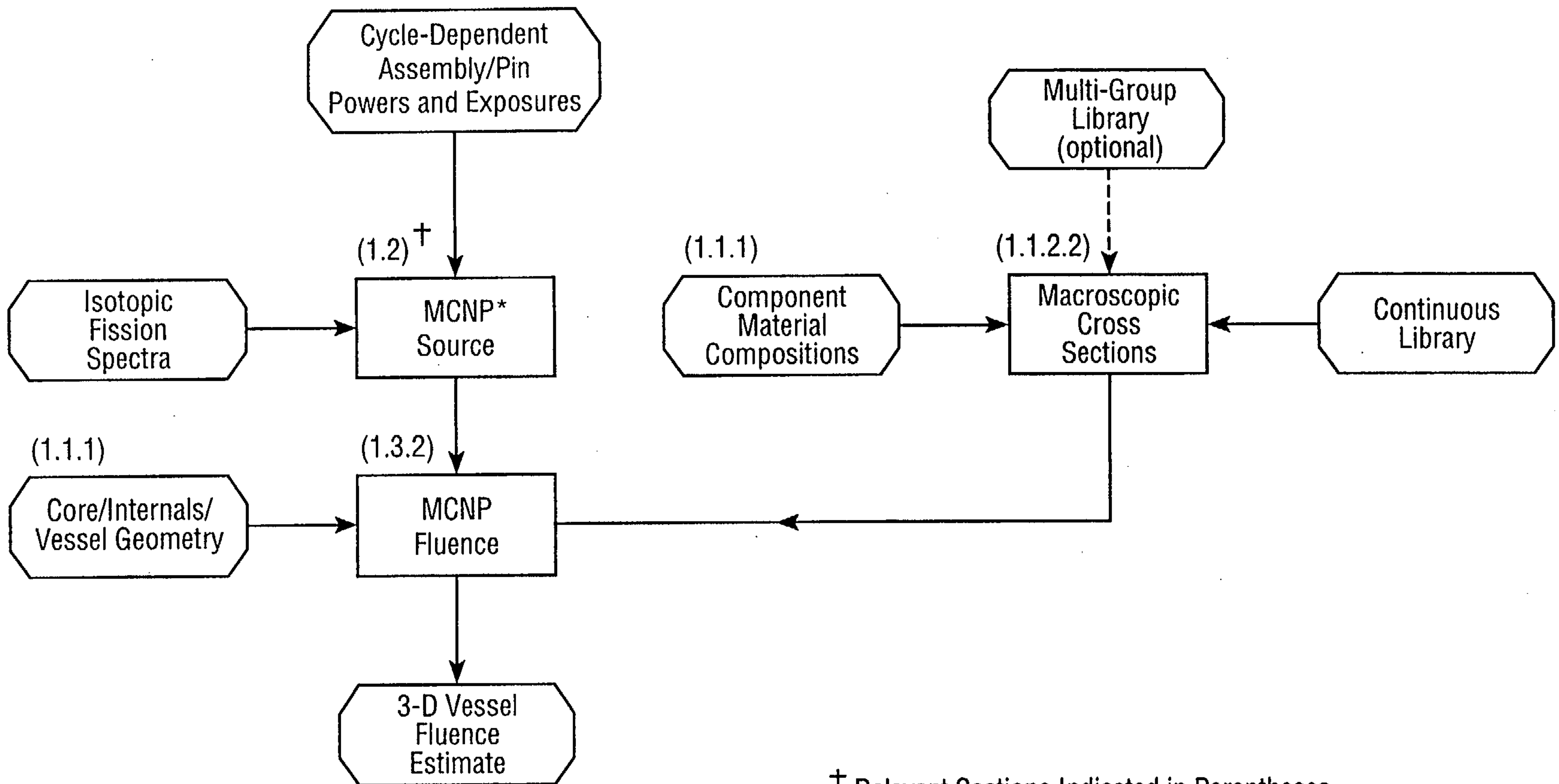
Discrete Ordinates C lculation Methodology



† Relevant Sections Indicated in Parentheses.
* The DOT code is used as an example.

FIGURE 1

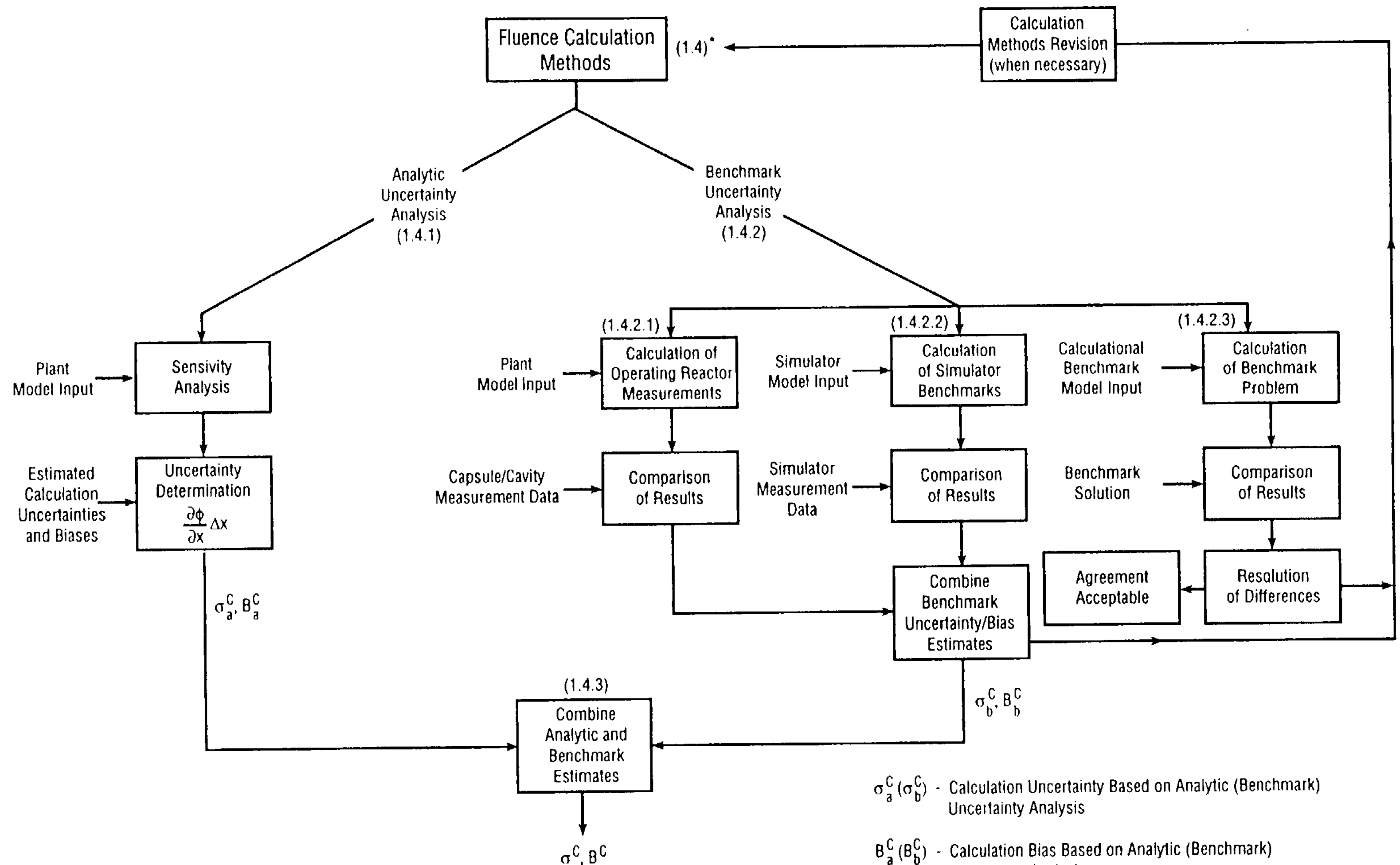
Monte Carlo Calculation Methodology



† Relevant Sections Indicated in Parentheses.
* The MCNP code is used as an example.

FIGURE 2

Calculation Methodo' · Qualification Procedure



σ_a^C (σ_b^C) - Calculation Uncertainty Based on Analytic (Benchmark) Uncertainty Analysis

B_a^C (B_b^C) - Calculation Bias Based on Analytic (Benchmark) Uncertainty Analysis

σ^C (B^C) - Estimated Calculation Uncertainty (Bias)

*Relevant Sections Indicated In Parentheses

FIGURE 3

Fluence Determination

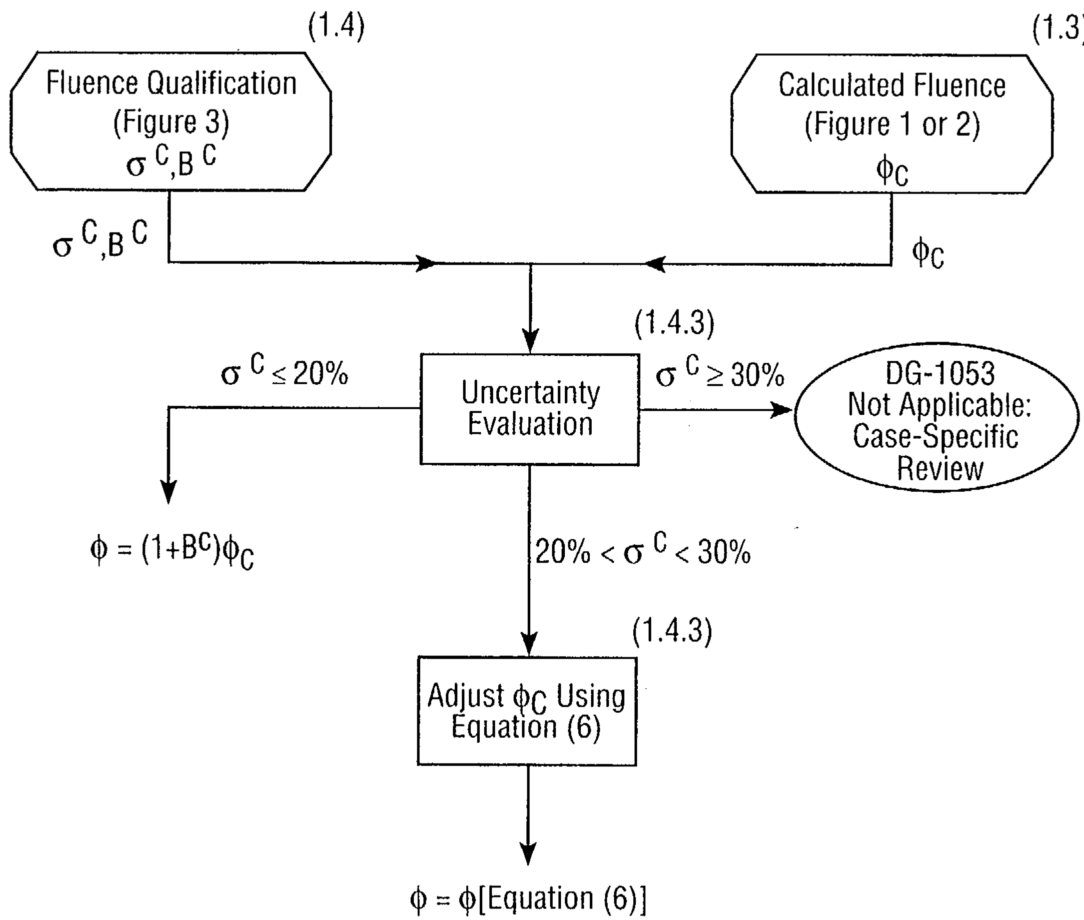
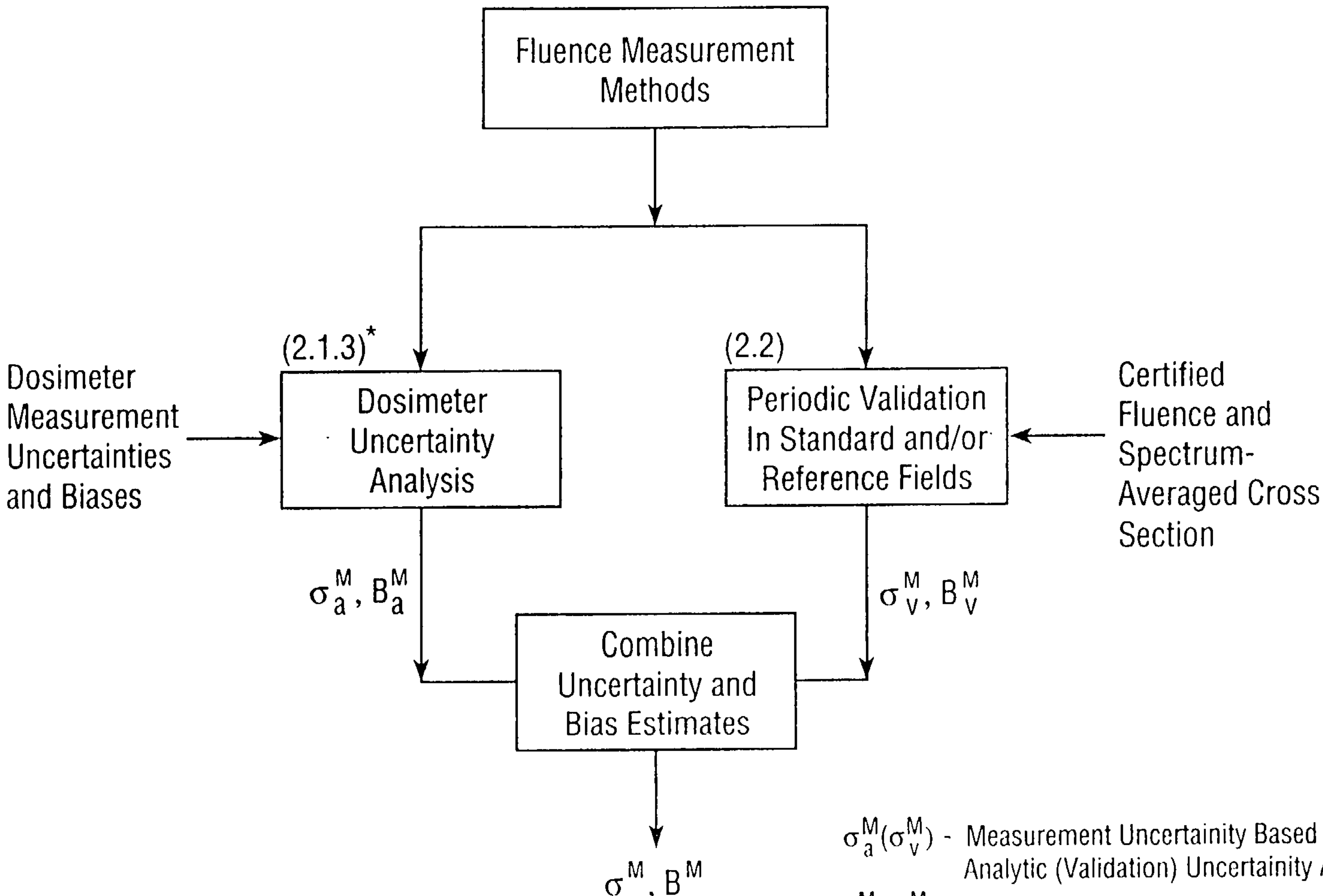


FIGURE 4

Measurement Qualification Procedure



$\sigma_a^M(\sigma_v^M)$ - Measurement Uncertainity Based on Analytic (Validation) Uncertainity Analysis

$B_a^M\ (B_v^M)$ - Measurement Bias Based on Analytic (Validation) Uncertainity Analysis

$\sigma^M(B^M)$ - Estimated Measurement Uncertainity (Bias)

* Relevant Sections Indicated In Parentheses

Figure 5

Summary of Regulatory Guide DG-1053

- Fluence Calculational Methods
  - Best-Estimate Rather Than Bounding Approach
  - Provides Accuracy of < 20% (1-σ)
  - Energy Range from 15 MeV to 0.1 MeV
- Qualification Via Benchmarking and Uncertainty Analysis

Summary of Regulatory Guide DG-1053

- Applicability
  - Fluence Input for Appendix-G and Reg. Guide 1.99
  - Both PWR and BWR Core/Vessel Geometries and Fuel Designs
  - Vessel Fluence Reduction Designs (PLSAs, Low-Leakage Cores, etc.) and Life Extension Calculations

Status of Regulatory Guide DG-1053

- NRC Pre-Release Reviews (1993)
  - ACRS Subcommittee
  - ACRS Committee
  - CRGR
- NRC Release for Comment
- Formal Review Meeting with Industry
- Round-1 Industry Comments Evaluated and Incorporated where Appropriate

Status of Regulatory Guide DG-1053

- September 18, 1996 Meeting with Industry to Review DG-1053
- Round-2 Industry Comments Evaluated and Incorporated where Appropriate
- Incorporation of Monte Carlo Transport Methods and BWR Benchmark Problem in DG-1053 and NUREG-6115
- September 28, 1999 NRC/Industry Meeting to Review DG-1053

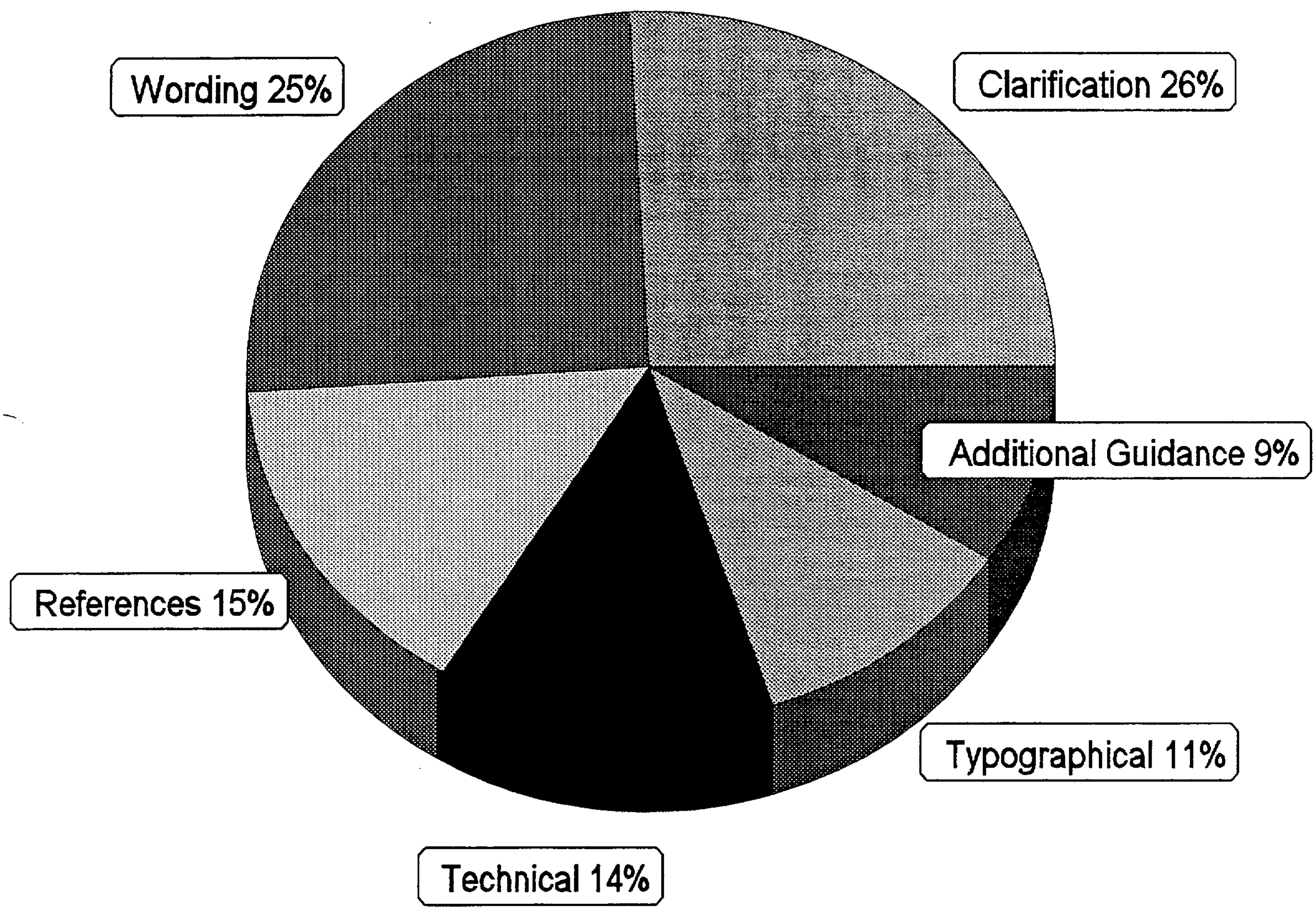
Status of Regulatory Guide DG-1053

- September 28, 1999 - Industry Requests Resolution of Comments Document (RCD) which Provides Basis for Resolution of Previous Comments
- March 2000 - Resolution of Comments Document Provided for Stakeholders Review
- May 2000 - Industry Comments on DG-1053 Received
- August 2000 - Evaluation of Industry Comments Completed and Appropriate Changes Incorporated in DG-1053
- Early 2001 - Final Release of Regulatory Guide

Resolution of DG-1053 Comments

- Resolution of Comments
  - Comments from: NEI, PSU (A. Haghighat), Bechtel Power (W. C. Hopkins) and DWM
  - Concerned editing, organization, methods and qualification
  - Includes recommendations to both relax and tighten requirements
  - Response to <u>all</u> comments and decision basis
  - Response based on Team consensus
  - Resulting changes and additions included in DG-1053

COMMENT TYPES



Resolution of DG-1053 Comments

- Comment Resolution Approach
  - All comments thoroughly evaluated for possible inclusion
  - Requirements for inclusion
    - Consistent with scope and purpose
    - Technically valid
    - Significant part of fluence determination
    - Consistent with presently accepted methods
    - Level of detail not overly prescriptive and should allow sufficient freedom to apply engineering judgement
  - Response based on Team consensus
  - Resulting changes/additions included in DG-1053

RESPONSES TO THE GENERAL COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
1) Comment: The final version of NUREG-6115 should be released.	1) Response: The draft version of NUREG/CR-6115 was released in September 1999. The final version of NUREG/CR-6115 will be published in early calendar 2001.
2) Comment: NEI recommends a standard problem round robin exercise among the NRC contractor and industry participants using the draft regulatory guide.	2) Response: The proposed round robin is outside the scope of the DRG-1053. The Guide provides highly detailed guidance on the methods for measuring and calculating fast neutron fluence which satisfy the requirements of both Appendix-G to Part 50 and 10 CFR 50.61. These methods have been employed in several measurement benchmark analyses which have been referenced and are publicly available. The NUREG/CR-6115 Benchmark Problem calculations will be available in early calendar 2001.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
1) Comment: The Resolution of Comments Document includes responses with insights that would be beneficial to the user of the Guide. Specifically Responses IV.8.3, IV.10.3, V.42.3, VI.16.3, VIII.5.3, VIII.12.3 and IX.3.3.	1) Response: Responses IV.8.3, IV.10.3 have been added to the Guide. Responses V.42.3 and VIII.5.3 were included as part of a previous update. Responses VI.16.3, VIII.12.3 and IX.3.3 are considered too detailed and/or are outside the scope of the Guide and are not being included
6) Comment: The Guide should include a reference to ASTM Standard E693 for characterizing neutron exposures of iron and low alloy steels in terms of displacements per atom (dpa), ASTM Standard E-2005 for benchmark testing and ASTM Standard E-1018 for the selection of dosimetry cross sections.	6) Response: The references for these ASTM standards have been added.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
Comments	**Responses**
18) Comment: The Monte Carlo energy bin structure for determining the dosimeter response should satisfy the same requirements as the broad multi-group energy structure given in Regulatory Position 1.1.2.	18) Response: The text has been revised to state that "to insure an accurate integration over the dosimeter cross section, the energy bin structure used to determine dosimeter response scoring should satisfy the requirements of Regulatory Position 1.1.2 concerning the selection of the multi-group library group structure."
21) Comment: The statistical acceptance criteria presented are generally specific to the MCNP Monte Carlo code and should be presented as an example rather than as a minimum set of criteria.	21) Response: The wording in the Guide has been changed to indicate that the statistical criteria are a representative set rather than a minimum set.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
27) <u>Comment</u>: (a) Additional guidance should be provided indicating how the uncertainty estimates based on the operating reactor measurements and the simulator benchmarks are to be combined to determine the fluence uncertainty estimate.	27) <u>Response</u>: (a) "Because the weighting of the analytic and benchmark uncertainty estimates depends on the details of the specific application which can vary widely, it is not possible to specify a practical and generically valid prescription for determining the weights. However, the following example illustrates factors that should be considered. In the case where as-built measurements of the vessel diameter are available and reasonable estimates of the core neutron source and other input uncertainties can be determined, the analytic uncertainty estimate should be very reliable and its weight may be increased to $w_A = 0.5$. If, in addition, there are a substantial number ($\gtrsim$ 10) of accurate($\sigma \lesssim$ 5%) operating reactor measurements, the weighting of the uncertainty estimate based on this data may be set to $w_O = 0.3$. The weighting of the uncertainty estimate based on the vessel simulator measurements is then $w_S = 0.2$."

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
27) Comment: (b) Additional guidance on how the calculation of the benchmark problem will be used to determine the fluence uncertainty should be provided.	27) Response: (b) As suggested, the benchmark problem calculation will be used as a "go/no-go" test rather than as an estimate of the fluence uncertainty. The text of Section 1.4.2.3 has been modified to reflect this change.
32) Comment: The analytic uncertainty analysis requires that model parameter sensitivity calculations be performed. The Guide states that, in some cases, the Monte Carlo sensitivity calculations will require that the change in the model parameter be increased to provide a reliable estimate of the sensitivity. Also, since the sensitivities are not generally linear, additional calculations may be required to determine the nonlinear dependence of the sensitivity.	32) Response: Additional text has been added noting that the dependence of the sensitivity on the perturbed parameter may not be linear and, if the parameter is significantly outside the parameter one-sigma standard deviation, several calculations may be required to determine the nonlinear dependence of the sensitivity.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
Comments	**Responses**
37) Comment: (a) While guidance on the agreement between measured and calculated integral quantities is provided, no guidance on the expected agreement for group fluxes is given. (b) DG-1053 does not define the bias.	37) Response: (a) The requirement to compare measured and calculated group fluxes has been removed. (b) A reference for the bias has been added to Footnote-1.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
37) Comment: (c) More information is required on the level of detail required for benchmark analysis.	37) Response: (c) The benchmark analysis of Section 1.4 requires the calculation of (1) a pressure vessel simulator (e.g., the PCA or PSF measurements) (2) operating reactor dosimetry measurements (either in-vessel, cavity or both) and (3) the NUREG-6115 benchmark. References 65, 72 and 73 provide several examples of benchmark analyses. References 74, 75 and 79 have been added to provide additional examples of benchmark analyses. Calculations of operating reactor dosimetry are well known throughout the industry and are performed for both in-vessel capsules and cavity measurements. Analyses of the benchmark problems are documented in NUREG-6115. The information provided in the references cited in the Guide is considered sufficient detail for performing benchmark analyses.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
40) Comment: (a) The referenced simulator benchmarks (References 5, 44, 58-63) and the calculation benchmark (NUREG-6115) do not provide sufficient detail to perform the benchmark calculations.	40) Response: (a) The NUREG-6115 report provides a complete definition of the benchmark problem except for the neutron source which is provided on a separate computer disc. References 74, 75 and 79 have been added to complete the documentation of the benchmarks.
(c) There are no results available that use the DG-1053 method.	(c) The NUREG-6115 Report includes benchmark results that have been determined using the DG-1053 method.
(d) BUGLE-96 is the latest version of the BUGLE cross section data and DOORS is the latest version of the DORT program. These versions of the nuclear data and transport code should be used to analyze the NUREG-6115 benchmark problem.	(d) The codes and nuclear data are being updated continuously. Changes included in the BUGLE-96 nuclear library and the DOORS code are presently being evaluated. If these changes have a significant effect on the application of the NUREG-6115 benchmark problems and there is a need to issue a revision to NUREG-6115, this will be considered.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
40) Comment: (b) Additional guidance on the use of NUREG-6115 in qualifying the calculational methods and what constitutes an acceptable solution should be provided.	40) Response: (b) The following guidance has been added: "The calculation of the benchmark problems allows a detailed assessment and verification of the numerical procedures, code implementation, and the various modeling approximations relative to state-of-the-art solutions for representative operating configurations. If the differences between the benchmark problem calculation and the reference solution are substantially larger than what would be expected based on the differences in the methods approximations and nuclear data used in the two calculations, the agreement is considered unacceptable. In this case, the calculation should be reviewed and the differences between the two solutions explained. When the cause of the deviation is determined to be an error in the calculation, the calculational method must be revised."

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
40) Comment: (e) In addition to the solutions calculated with DORT and MCNP, the NUREG-6115 Report should provide reference solutions calculated with different codes such as TWODANT and MCBEND.	40) Response: (e) While the use of the TWODANT and MCBEND codes will provide an indication of the code-to-code variation, in view of the extensive benchmarking and testing of these codes, the uncertainty introduced by the code selection is very small when compared to the uncertainty in the plant fluence calculations. Consequently, the use of the DORT and MCNP codes in performing the calculations of NUREG-6115 is considered adequate.
(f) If the purpose of performing the NUREG-6115 benchmark calculations is to validate the implementation of DORT, the DORT electronic input and output files should be provided to insure that the modeling parameters are the same as used in NUREG-6115.	(f) The purpose of the NUREG-6115 benchmark calculations is to validate both the implementation of DORT and the fluence calculation modeling techniques. Providing the DORT electronic files would prevent the validation of the modeling techniques which is considered to be most important.

RESPONSES TO THE COMMENTS PROVIDED BY THE NUCLEAR ENERGY INSTITUTE	
Comments	**Responses**
51) Comment: The term "every few years" in the statement "to ensure long-term consistency and to confirm measurement uncertainty, dosimetry measurements must be performed every few years in well characterized neutron fields," should be quantified. 55) Comment: The guidance conflicts with the least-squares approach.	51) Response: Because of the differences between the various measurement systems and procedures, this period has been purposely left unquantified in order to allow the needed flexibility in its application. 55) Response: While the Guide allows the use of the Least-Squares Adjustment (LSA) method, many licensees do not employ this method and, consequently, the guide provides guidance on both approaches. Where appropriate, the guide has been revised to remove conflicts between the two methods. The suggested wording has been added.

RESPONSES TO THE COMMENTS PROVIDED BY THE PENNSYLVANIA STATE UNIVERSITY A. Haghighat	
Comments	**Responses**
1) Comment: Because of the axial variation of the BWR void distribution, the source and material distributions require three-dimensional representations. Consequently, it is not evident that the DG-1053 methodology is applicable to BWRs. 16) Comment: The verification of the variance reduction method used in the fluence calculation is impractical/impossible.	1) Response: The DG-1053 methodology is applied to a typical BWR in NUREG-6115 and shown to be applicable to BWRs. 16) Response: The variance reduction method is an approximation that can have a substantial effect on the calculated fluence. Consequently, this method should be verified to ensure the fluence prediction is reliable. The Guide states that the verification of the variance reduction method should be qualified by comparing the Monte Carlo variance reduction predictions with estimates made without the application of the variance reduction technique. This verification method has been used successfully in the Monte Carlo analyses of NUREG-6115.

RESPONSES TO THE COMMENTS PROVIDED BY BECHTEL POWER CORP. William C. Hopkins	
Comments	**Responses**
2) Comment: The attached figure should be included in the Guide to clarify the dependence of the fluence determination on the fluence uncertainty.	2) Response: The proposed figure provides a significant clarification of the procedure used to determine the fluence and will be included (as Figure-4) in the Guide.

NUREG/CR-6115 Pressure Vessel Fluence Benchmark Problems

- Purpose
  - Insure accurate fluence predictions and quantify uncertainty
  - Standardize vessel fluence methods
  - Streamline licensing process

Application of Benchmark Problems

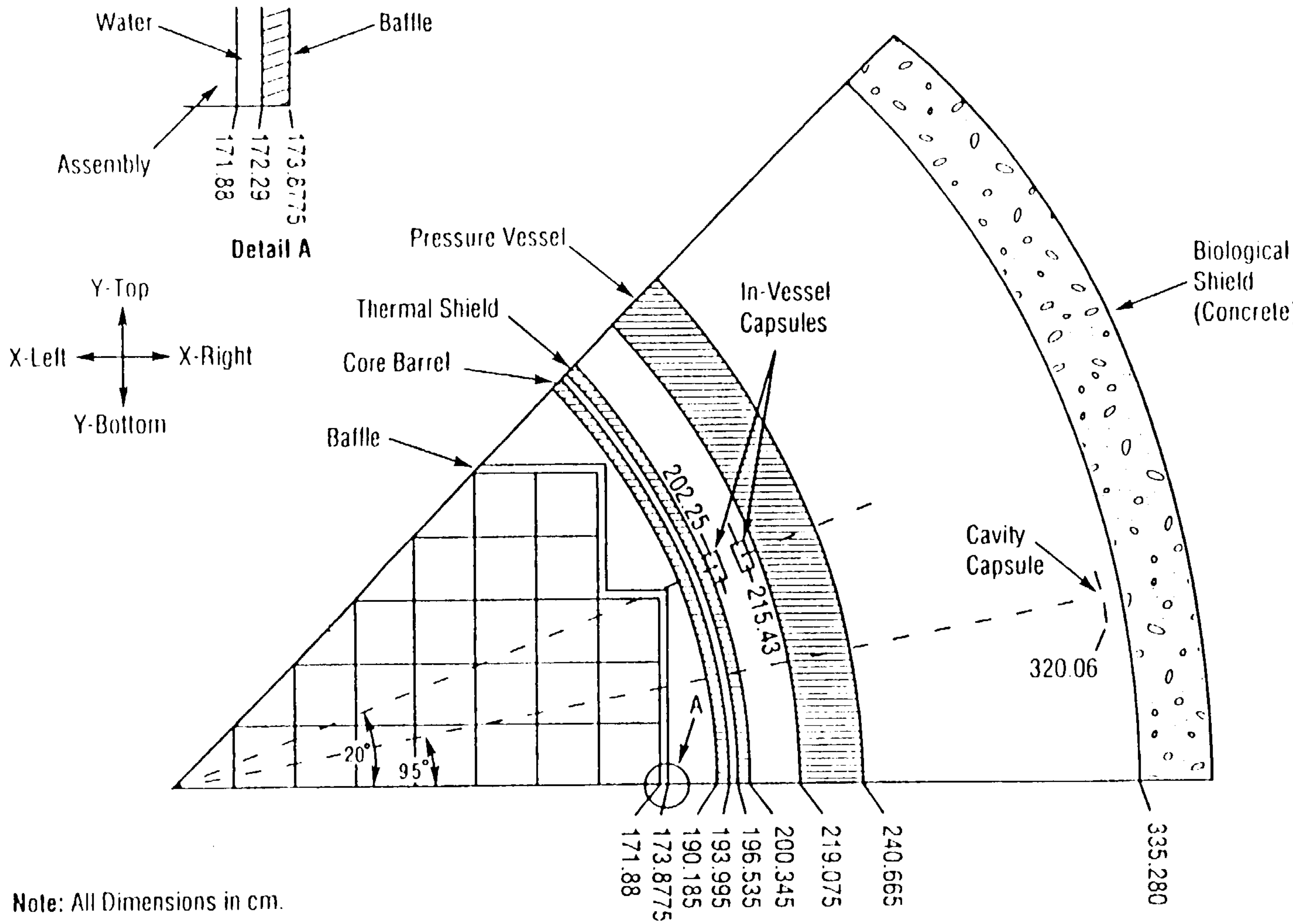
- Fluence Methods Provided in DG-1053
- NUREG/CR-6115 Provides Problem Definitions and Reference Solutions
- Licensee Calculates the Benchmark Problems
- Comparisons to the Reference Solutions Provided to NRC
- Fluence Methods Accepted (in part) Based on Agreement with Reference Solutions

Problem Definition

- Core Types Include
  - PWR - Standard Core, Low-Leakage Core (LL), and Partial Length Shield Assembly (PLSA) Core
  - BWR - Standard Core
- Detailed Description of Problem Materials, Geometry and Pin-Wise Source
- Typical Operating Reactor Geometry and Materials
- Complete Fluence Analysis Involving the Execution of Steps Required for the Determination of RT_{PTS} Input

PWR Standard Core Benchmark Problem

- Geometry
  - Typical core-to-cavity dimensions and materials including a thermal shield and biological shield
- Core Neutron Source
  - Pin-wise power distribution with fuel isotopics vs burnup
- Complete and Detailed Set of Calculation Input Provided
- Dosimeters Located in Standard Wall Capsule and in Cavity
- ENDF/B-VI Dosimeter Cross Sections Provided

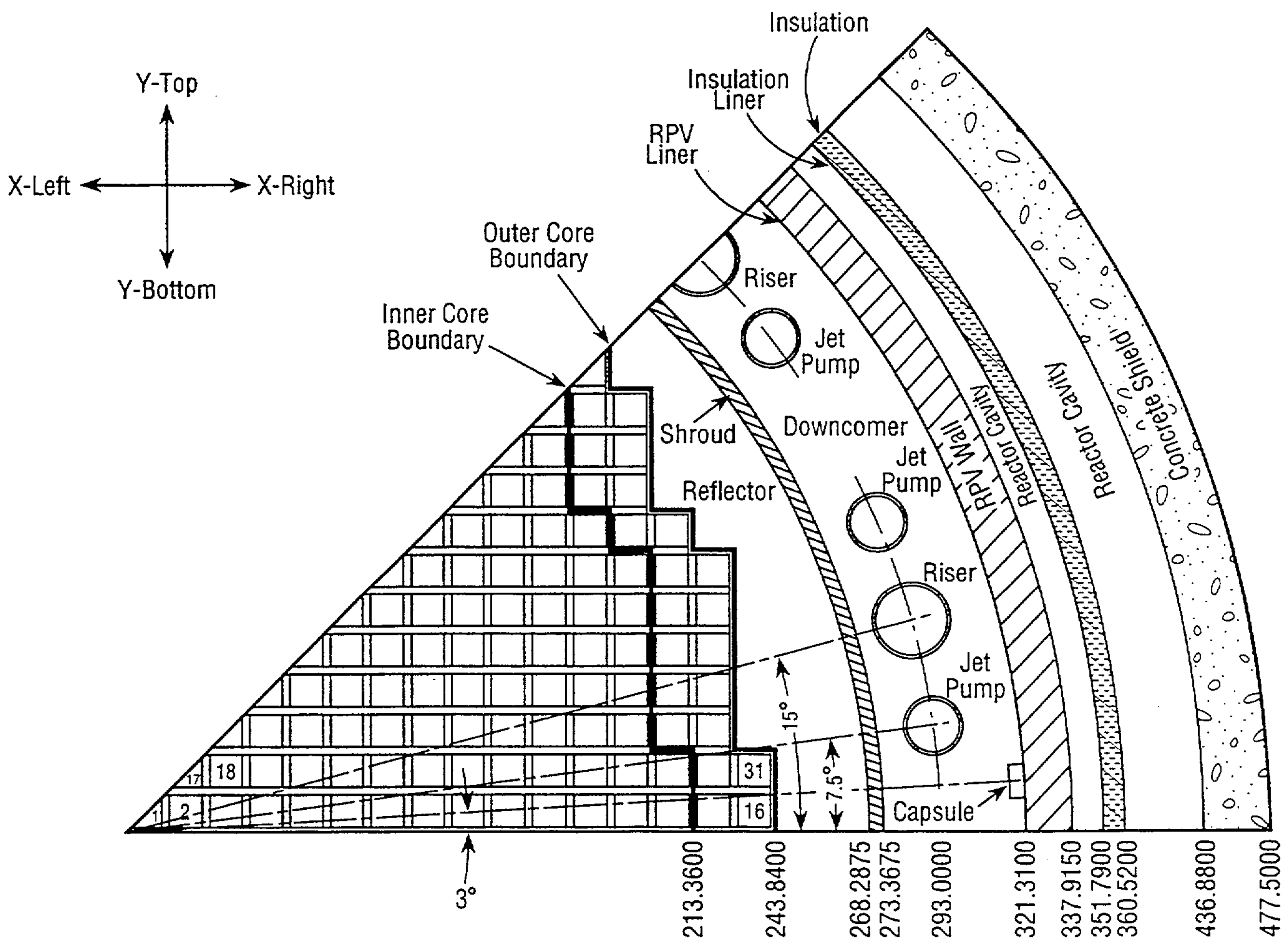


Location of Surveillance Capsules

Fig. 2.2.3

Figure 2.2.2.1

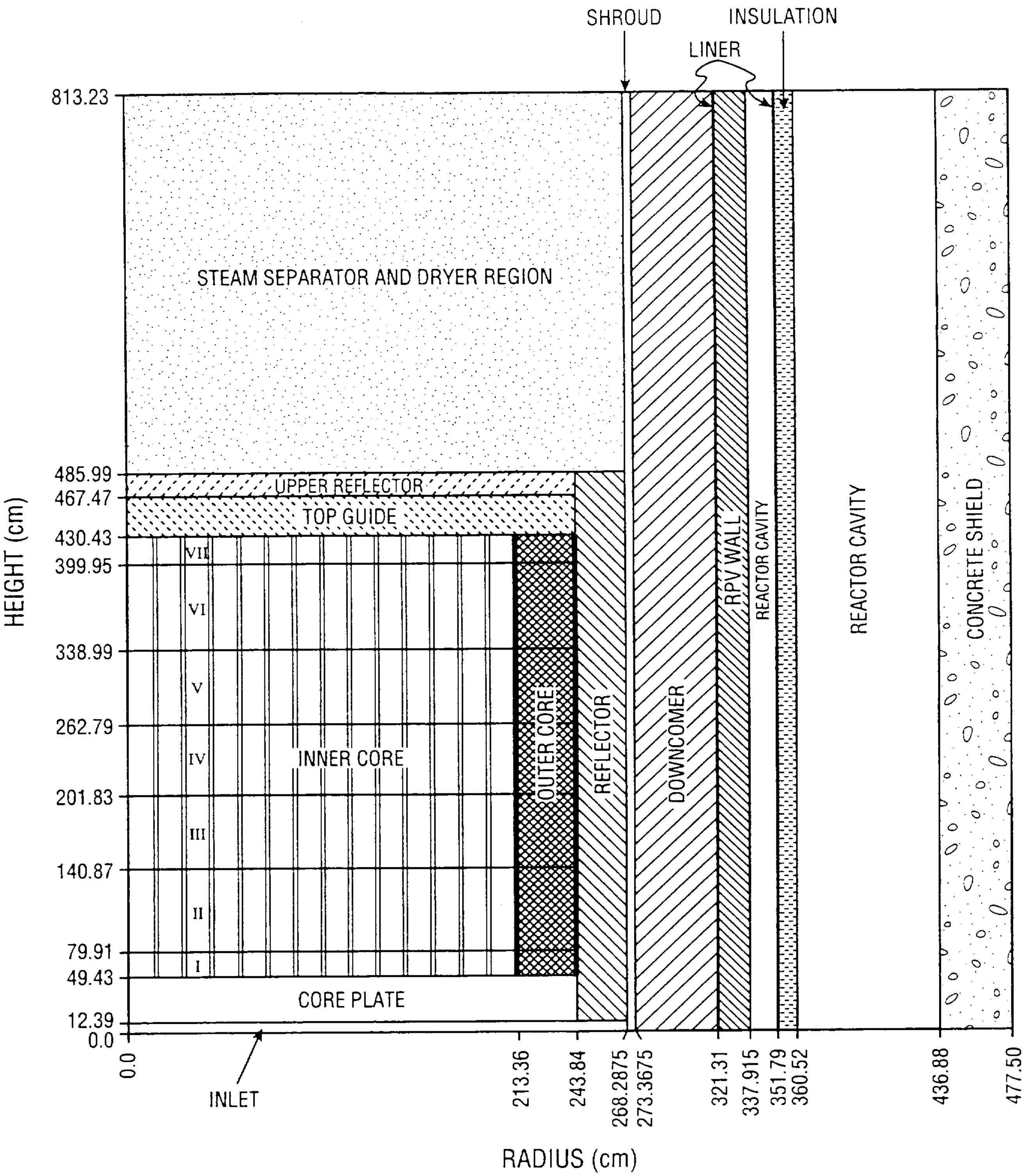
BWR Planar Geometry



NOTE: All Dimensions in cm

Figure 2.2.2.2

BWR Axial Geometry



NOTE: All Dimensions in cm

Table 2.2.1

Standard Core Loading

Basic Design Data

Reactor		Material
Thermal Power	2527.73 MW(TH)	--
Core Inlet Temp.	536 °F	--
Core Operating Pressure	2010 psia	--
Baffle Thickness	1.5875 cm	SS-304
By-Pass	--	H_2O (560 °F 2010 psia)
Inner Radius of Core Barrel	190.185 cm	--
Barrel Thickness	3.81 cm	SS-304
Inner Inlet Thickness	2.54 cm	H_2O (536 °F 2010 psia)
Inner Radius of Thermal Shield	196.535 cm	--
Thermal Shield Thickness	3.81 cm	SS-304
Outer Inlet Thickness	18.095 cm	H_2O (536 °F 2010 psia)
Inner Radius of Liner Clad	218.440 cm	--
Vessel Liner Clad Thickness	0.635 cm	SS-304
Vessel Thickness	21.59 cm	SA-302B
PV Insulation Air Thickness	1.835 cm	Air
PV Insulation Thickness	10.16 cm	PV Insulation
Cavity Thickness	82.62 cm	Air
Inner Radius of Biological Shield	335.280 cm	--
Bio-Shield Liner Thickness	0.635 cm	SA-302B
Bio-Shield Thickness	213.36 cm	Concrete

Table 2.2.3

Standard Core Loading

Design Specification Material Compositions

Mixture	Component	Atom Densities (atom/b*cm)
Core	H	2.82500E-02
	B	2.69200E-05
	O	1.41200E-02
	C	2.58100E-05
	O (fuel)	1.28500E-02
	Al	3.56000E-04
	Cr	1.60800E-05
	Fe	2.20500E-05
	Ni	3.87700E-05
	Zr	5.44800E-03
	U-235	1.12000E-04
	U-238	6.03000E-03
	Pu-239	2.20000E-05
	Pu-240	7.12000E-06
Baffle (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Bypass+ (560 F)	H	4.92900E-02
	O	2.46400E-02
	B	4.90000E-06
Core Barrel (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Inlet Water Gap (536 F)	H	5.09600E-02
	O	2.54800E-02
	B	5.10000E-06
Thermal Shield (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
RPV Liner (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Cavity (Air)	N	3.20000E-05
	O	8.00000E-06

+This composition is also to be used in the water region between the fuel assembly and the core baffle (see Figure 2.2.1).

Benchmark Problem Solution

- Tabulated Solution Based on Standard Fluence Analysis Predictions
- Problem Solution Includes
  - Fluence > 1-MeV, > 0.1 MeV, dpa and spectrum
  - Accelerated and wall capsules and vessel internal and cavity locations
  - Dosimeter reaction rates at capsule and cavity locations
  - Fluence sensitivity calculations

Benchmark Problem Solution

- Calculational Methods Based on DG-1053
  - DORT S_8 P_3 transport
  - (r, θ) / (r,z) synthesis
  - BUGLE-93 / ENDF/B-VI cross sections
  - ENDF/B-VI dosimeter cross sections provided
  - ENDF/B-VI fission spectrum

Table 4.2.1

Standard Core Loading

Flux (E>1.0 MEV) At Pressure Vessel

z	125.488cm	125.488cm	129.186cm	129.186cm	140.282cm
θ	0-T	1/4 T	1/2 T	3/4 T	T
1	3.14799E+10	1.78931E+10	8.69114E+09	4.00968E+09	1.63867E+09
2	3.14939E+10	1.78948E+10	8.69181E+09	4.01204E+09	1.63590E+09
3	3.15515E+10	1.79309E+10	8.71023E+09	4.01916E+09	1.63546E+09
4	3.18090E+10	1.80707E+10	8.77347E+09	4.04608E+09	1.64438E+09
5	3.22184E+10	1.82947E+10	8.87711E+09	4.09152E+09	1.65943E+09
6	3.27523E+10	1.85911E+10	9.01599E+09	4.15139E+09	1.67925E+09
7	3.34669E+10	1.89955E+10	9.20569E+09	4.23439E+09	1.70608E+09
8	3.44603E+10	1.95427E+10	9.45942E+09	4.34323E+09	1.74117E+09
9	3.54574E+10	2.00747E+10	9.70318E+09	4.44796E+09	1.77511E+09
10	3.63728E+10	2.05806E+10	9.93677E+09	4.54712E+09	1.80693E+09
11	3.74744E+10	2.11727E+10	1.02041E+10	4.66105E+09	1.84307E+09
12	3.85964E+10	2.17730E+10	1.04749E+10	4.77398E+09	1.87884E+09
13	3.96873E+10	2.23491E+10	1.07308E+10	4.88026E+09	1.91205E+09
14	4.06848E+10	2.28693E+10	1.09581E+10	4.97269E+09	1.94069E+09
15	4.15408E+10	2.33066E+10	1.11436E+10	5.04551E+09	1.96229E+09
16	4.22000E+10	2.36185E+10	1.12659E+10	5.08990E+09	1.97516E+09
17	4.25965E+10	2.37640E+10	1.13064E+10	5.09949E+09	1.97593E+09
18	4.25805E+10	2.36866E+10	1.12453E+10	5.06928E+09	1.96689E+09
19	4.21634E+10	2.34630E+10	1.11362E+10	5.02312E+09	1.95418E+09
20	4.20061E+10	2.32440E+10	1.10309E+10	4.98065E+09	1.93913E+09
21	4.11917E+10	2.27246E+10	1.08174E+10	4.90050E+09	1.91354E+09
22	4.02185E+10	2.21933E+10	1.06133E+10	4.82491E+09	1.89446E+09
23	3.88038E+10	2.17186E+10	1.04642E+10	4.77406E+09	1.88876E+09
24	3.82263E+10	2.15915E+10	1.04226E+10	4.75869E+09	1.88401E+09
25	3.73962E+10	2.12952E+10	1.03327E+10	4.72600E+09	1.86809E+09
26	3.67420E+10	2.09653E+10	1.02152E+10	4.68137E+09	1.85169E+09
27	3.63552E+10	2.07451E+10	1.01082E+10	4.63723E+09	1.83997E+09
28	3.64033E+10	2.06613E+10	1.00430E+10	4.60702E+09	1.83573E+09
29	3.65714E+10	2.06166E+10	1.00083E+10	4.59093E+09	1.83048E+09
30	3.70498E+10	2.05760E+10	9.92482E+09	4.54562E+09	1.80541E+09
31	3.68078E+10	2.04258E+10	9.81075E+09	4.48443E+09	1.78065E+09
32	3.62594E+10	2.02359E+10	9.70994E+09	4.43473E+09	1.76407E+09

MCNP Calculations of Benchmark Problems

- Based on NUREG/CR-6115 Problem Definitions
  - Standard core
  - PLSA core
  - BWR core
- Exact Three-Dimensional Geometry
  - Explicit core/baffle/shroud/barrel geometry
  - Pin-wise source description for peripheral assemblies
- Multi-Group ENDFB/VI Library Based on BUGLE-93

MCNP Calculations of Benchmark Problems

- Region-Wise Importance Weighting
- > 1-MeV Fluence Edit at Selected Vessel Inner-Wall Locations
- DORT/MCNP Differences ≤5% Consistent with Methods Uncertainties
  - MCNP statistics
  - DORT geometry
  - DORT numerics
  - DORT synthesis

Fig. 5.3.7

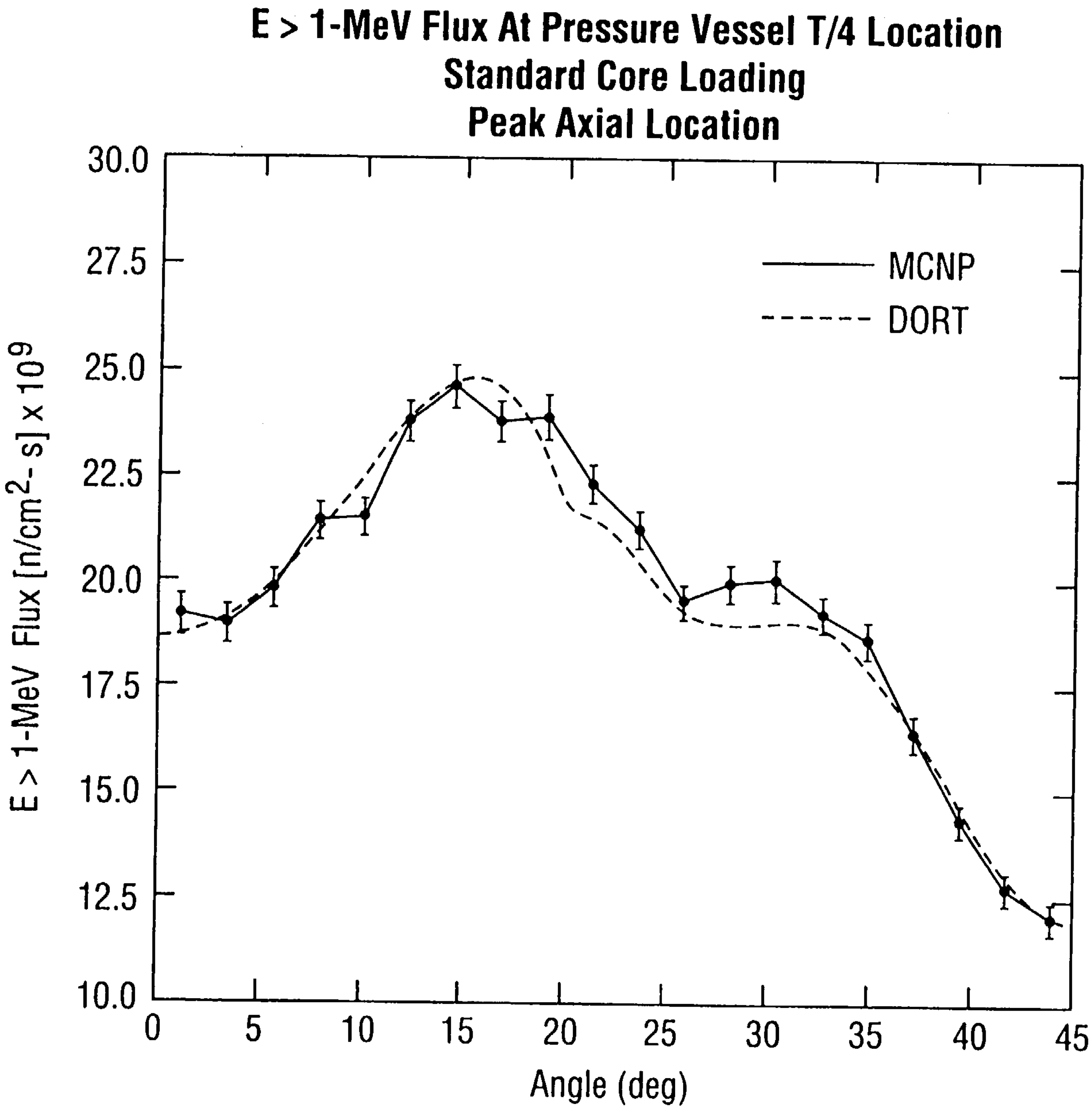

E > 1-MeV Flux At Pressure Vessel T/4 Location
Standard Core Loading
Peak Axial Location
MCNP
DORT
E > 1-MeV Flux [n/cm2- s] x 109
Angle (deg)
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
0
5
10
15
20
25
30
35
40
45

Figure 5.3.9

E > 1-MeV Flux At Pressure Vessel Lower Weld
Partial Length Shield Assembly Core Loading

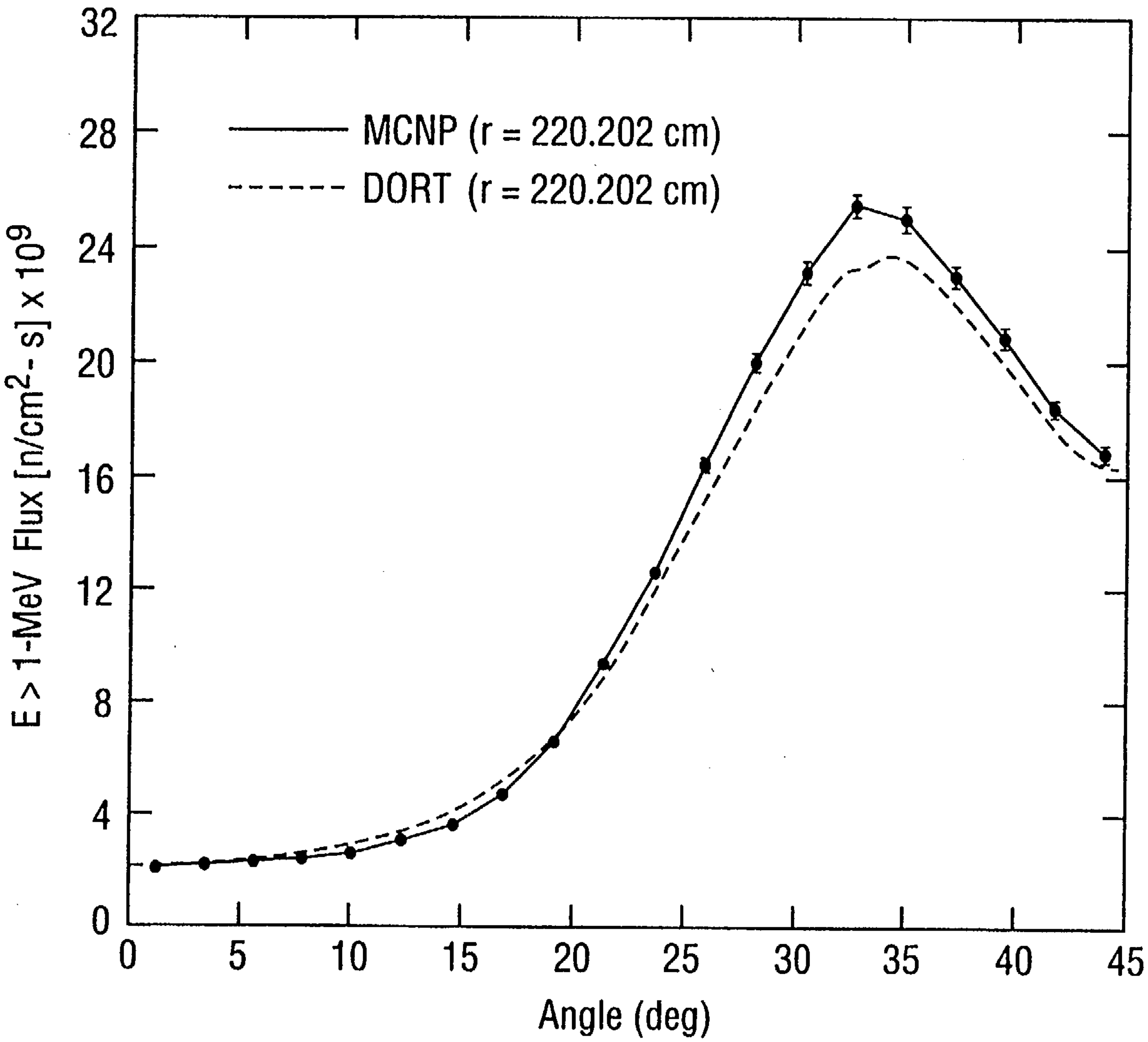


Figure 5.4.5

Comparison of MCNP and DORT E > 1-MeV Flux In Downcomer (r= 278.10 cm) at The Core Axial Midplane

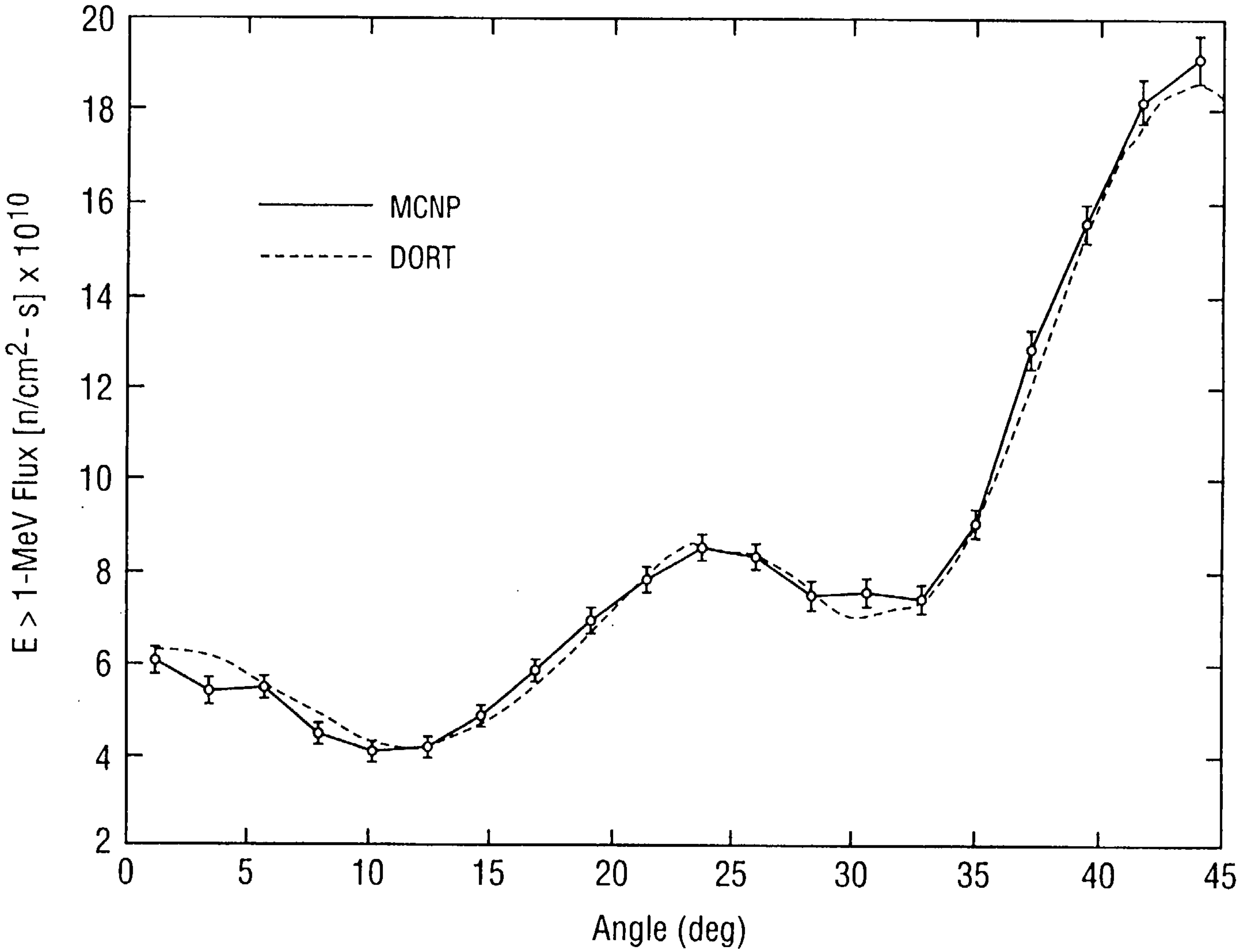


Figure 5.4.7

E > 1-MeV Flux In Downcomer (r = 278.10 cm) at The Core Axial Midplane With Probable Error