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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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SUBCOMMITTEE ON RADIATION PROTECTION AND NUCLEAR

MATERIALS

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TUESDAY

JULY 10, 2012

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear  
Regulatory Commission, Two White Flint North, Room  
T2B3, 11545 Rockville Pike, at 8:30 a.m., Michael T.  
Ryan, Chairman, presiding.

COMMITTEE MEMBERS:

MICHAEL T. RYAN, Chairman

J. SAM ARMIJO

DANA A. POWERS

HAROLD B. RAY

JOHN D. SIEBER

1 GORDON R. SKILLMAN

2

3 NRC STAFF PRESENT:

4 CHRISTOPHER L. BROWN, Designated Federal

5 Official

6 MERAJ RAHIMI

7 DREW BARTO

8 BRIAN WAGNER

9

10 ALSO PRESENT:

11 JOHN WAGNER

12 ALBERT MACHIELS

13 MARCUS NICHOL

14 DALE LANCASTER

15

P-R-O-C-E-E-D-I-N-G-S

8:30 a.m.

CHAIR RYAN: Alrighty, good morning everybody. The meeting will now come to order. This is a meeting of the Advisory Committee on Reactor Safeguards, Subcommittee on Radiation Protection Nuclear Materials. I'm Michael Ryan, Chairman of the Subcommittee.

Subcommittee members in attendance are Dana Powers, Sam Armijo, Harold Ray. Let's see. Dick Skillman is here, Steve Schultz is not yet here.

MEMBER POWERS: No, he's not going to be here.

CHAIR RYAN: And Jack Sieber is here and Dana Powers. The Subcommittee will hear presentations by and hold discussions with representatives of the NRC staff, the Electric Power Research Institute and the Nuclear Energy Institute on ISG-8, Rev 3, burnup credit and the criticality safety analysis of PWR spent fuel in transportation and storage casks.

The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for deliberation by the full Committee. Christopher Brown is the Designated Federal Official for this meeting.

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1           The rules for participation in today's  
2 meeting have been announced as part of the notice of  
3 this meeting previously published in the *Federal*  
4 *Register* on June 26, 2012. A transcript of the  
5 meeting is being kept and will be made available as  
6 stated in the *Federal Register* notice.

7           It is requested that speakers first identify  
8 themselves and speak with sufficient clarity and  
9 volume so they can be readily heard. We ask at this  
10 time that you silence your mobile phones and other  
11 electronic devices.

12           The ACRS full Committee briefing is  
13 scheduled for September 6th, 2012. I might just make  
14 a short note, that this Subcommittee meeting follows  
15 onto work done by the former Advisory Committee on  
16 Nuclear Waste and Materials in 2007 and 2008, and I  
17 know they had a number of subcommittees and a couple  
18 of letters, and that work is available for reference,  
19 if anybody needs it.

20           We will proceed with the meeting, and I call  
21 upon Meraj Rahimi, branch chief of NMSS, to begin.  
22 Meraj, welcome and thanks for being with us.

23           MR. RAHIMI: Thank you very much, Dr. Ryan,  
24 thank you gentlemen, and my name is Meraj Rahimi. I'm  
25 the chief of the Criticality Shielding Dose Assessment

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1 Branch in the Division of Spent Fuel Storage and  
2 Transportation in NMSS.

3 What we're going to talk about today is  
4 burnup credit, this new revision of ISG-8. This is  
5 the, I think, the work that we believe that has been  
6 completed on burnup credit, the work in making over 20  
7 years, and this is the, really the closing chapter, we  
8 believe, on burnup credit for spent fuel storage and  
9 transportation cask in terms of providing complete  
10 guidance to the staff.

11 So this was actually quite a bit of work.  
12 I really want to acknowledge the people who really  
13 helped this work to come to fruition. Of course, this  
14 work was done in cooperation with NRR, NRO, Office of  
15 Research and the heavy lifting of the technical work,  
16 of course, Oak Ridge National Lab.

17 I want to acknowledge, you know, John Wagner  
18 from, you know, Oak Ridge National Lab, and especially  
19 I want to thank my team in the Criticality Branch,  
20 that we put together a team a couple of years ago to  
21 pull all the work together.

22 So again, I want to thank everybody for  
23 completing this work. So I think we're going to have  
24 a very good meeting, and especially we'll hear from  
25 the industry and with that, then let's go to the first

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1 slide.

2 MEMBER ARMIJO: I did have one real  
3 background question.

4 MR. RAHIMI: Yes.

5 MEMBER ARMIJO: And this is this is titled  
6 for PWR Spent Fuel. But the approaches should be  
7 applicable to BWR fuel as well. Now what is the staff  
8 going to do about that or what has the staff done  
9 about BWR fuel?

10 MR. RAHIMI: Right. This work is only about  
11 PWR, and we will address towards the end, we have just  
12 started the work on BWR. Some preliminary has been --  
13 some preliminary work has been done in the past few  
14 years on the BWR, a scoping study.

15 But as Drew will go over it at the end of  
16 his presentation, there is a plan for to write a  
17 separate ISG or revise this ISG for BWR burnup credit.

18 MEMBER ARMIJO: Okay, thank you.

19 MR. RAHIMI: So that's our agenda for this  
20 morning. So after I give the opening remarks, we'll  
21 give you a little bit of background, and Drew will  
22 cover really the overview of the ISG-8, in terms of  
23 the methodology and approach, and Brian Wagner from  
24 Office of Research will give a discussion on the  
25 misload probability, because this was one of the areas

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1 that, with the help of Research, we wanted to focus  
2 on, and I know that the Committee's very interested in  
3 this area. So we should have a very good discussion  
4 on the mislead probability.

5 And John Wagner from Oak Ridge, he will  
6 cover the detail of the technical basis for the ISG,  
7 which mainly focuses on the code validation, depletion  
8 code and the criticality code validation, the method.

9 And Drew will cover the public comments that  
10 we've got so far, and our strategy in responding to  
11 those public comments. We certainly one of the things  
12 we did not want to finalize this ISG. We did want to  
13 get the input from the Committee also on the ISG, and  
14 our strategy in responding to the comments that we've  
15 received.

16 I believe we will hear from industry, from  
17 Al Machiels, EPRI, later on, and Marc Nichol and the  
18 industry views on the ISG-8. So with that, let's go  
19 to the next agenda.

20 I just wanted to give you a little bit of  
21 background in terms of this is a public meeting, you  
22 know, in terms of any members of the public, you know,  
23 are here. Really going back to the 70's, you know,  
24 why burnup credit for casks. I mean that first bullet  
25 really goes back in the 70's, the older generation

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1 casks, the way they were designed. It was for younger  
2 fuel.

3 Basically, the idea was as soon as the fuel  
4 is discharged from reactor, it stays in the pool for  
5 a few months, or be shipped out to a reprocessing  
6 facility. So those casks in the 70's really were  
7 designed based on that concept.

8 So it was designed for a more younger fuel,  
9 and really subcriticality didn't come into play. It  
10 was mainly radiation and heat transfer. That was the  
11 driving parameters for the design.

12 MEMBER POWERS: That was because there  
13 wasn't much fuel in the cask?

14 MR. RAHIMI: I'm sorry?

15 MEMBER POWERS: There wasn't much fuel in  
16 the cask?

17 MR. RAHIMI: Yeah exactly, because we go  
18 back, analyze 1 PWR, 2 BWR casks. That was the old  
19 cask design. The rail cask design was, you know,  
20 transnuclear. It was, you know, 7 PWR. That was the  
21 60-70 ton cask, but there was flux trapping there. So  
22 really heat and radiation was, you know, driving the  
23 design.

24 I guess in the 80's and the 90's, with the  
25 new generation of cask design, I realize reprocessing

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1 is out of the pictures. They have to go to, you know,  
2 storage. So it's longer-cooled fuel. Therefore, the  
3 design is looking to increasing the payload capacity.

4 So with that subcriticality, now we've got  
5 more fuel than the cask. Subcriticality became one of  
6 the, you know, primary design drivers. Next slide.

7 So to achieve these high capacities, cask  
8 designers eliminated; basically, they wanted more  
9 real estate in that cask diameter. So they said okay,  
10 let's get rid of this flux trap. Flux trap is the  
11 spacing within fuel. Neutronics, you know, it helps  
12 you a lot, because you slow down the neutrons and  
13 you've got spaces, and they get absorbed in the poison  
14 plates.

15 So first thing they did, they got rid of the  
16 flux traps, so no spacing in there, and to get rid of  
17 that, the flux trap was based on the fresh fuel  
18 assumption. So they moved away from the fresh fuel  
19 assumptions into assuming the fuel is burned, which is  
20 the burnup credit comes into the picture.

21 What is burnup credit? It's just, you know,  
22 in designing your criticality controlled system of the  
23 cask, you take credit for reduction of reactivity that  
24 occurs with fuel burnup, due to depletion in the  
25 reactor core. That means that there is a net

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1 reduction of fissile isotopes.

2 I mean you reduce, you know, U-235. Of  
3 course, you produce Pu-239. But overall, there's a  
4 net reduction in the fissile isotopes, and mainly you  
5 produce a lot of neutron-absorbing isotopes, actinides  
6 and fission products. So that's basically really the  
7 burnup credit.

8 Let's go to the next slide. So back in  
9 2002, the staff, based on available data, started  
10 receiving application for burnup credit, and so we  
11 needed to put out a guidance for the staff to review  
12 these applications.

13 Based on the available data back then, we  
14 could only give credit, allow credit for actinides,  
15 because there were a lot of assay data, there were a  
16 lot of critical experiments that involved actinides,  
17 major actinide isotopes including U-235, plutonium.

18 So we had enough data, a lot of critical  
19 experiments. So that's what the staff could do at  
20 that time. So we issued ISG-8 Revision 2. Of course,  
21 you know, we used Revision 0 1998 and from 1998, you  
22 know, we made some modification, and in 2002, we  
23 should issued the guidance for to take credit for  
24 major actinides.

25 Then subsequently we had a SECY paper. We

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1 had an SRM from the Commission, and there was a  
2 general direction from the Commission saying that the  
3 staff should focus its effort on using burnup credit  
4 as a means to insert more realism into spent fuel  
5 transportation cask criticality analysis.

6 So we take that as going beyond actinides  
7 only. Though you may not have all the data in there,  
8 but you know, take a risk-informed approach. Of  
9 course, in 2008, from ACNWM, that the letter went to  
10 Chairman Klein.

11 That was in regard with another exclusion  
12 really leading, but the burnup credit came into play  
13 into discussion, and the recommendation from the  
14 Committee was that the staff take a risk-informed  
15 approach in evaluating burnup credits.

16 So since then, we've been in the pursuit of  
17 that approach, and what has resulted today, that we  
18 now issued, in May, we issued the ISG Rev 3, which now  
19 includes, provides guidance to taking credit for  
20 fission products, and we have addressed a number of  
21 other items, including the burnup verification  
22 measurement, because we got a lot of feedback,  
23 especially from industry, in terms of the physical  
24 measurement.

25 So now we've provided an alternative to

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1 physical measurement verification, and also we look at  
2 the other parameters. Like in ISG-8 Rev 2, the  
3 maximum burnup credit you could take up to 45  
4 gigawatt-days, now we've extended all the way to 60,  
5 because since from 2002, a lot of chemical assay  
6 became available.

7 So that gave us the ability, you know, to  
8 extend the range of the burnup credit, which Drew will  
9 go over those. So with that, I'll turn it over to  
10 Drew, to provide an overview of what we've done in  
11 ISG-8 Rev 3.

12 CHAIR RYAN: Thanks, Raj. Drew.

13 MR. BARTO: Thanks, Meraj. I'm Drew Barto.  
14 I'm a senior nuclear engineer in the Division of Spent  
15 Fuel Storage and Transportation in NMSS. I'm going to  
16 go over what are the major changes to ISG-8 from the  
17 last revision.

18 Probably the major change is that ISG-8 Rev  
19 2 recommended credit for only the major actinides for  
20 which we had sufficient data for co-validation for the  
21 depletion and criticality codes. With ISG-8 Rev 3, we  
22 are recommending additional credit for minor actinides  
23 and fission products. So that's an additional 18,  
24 actually I guess 20 isotopes that we'll get into, that  
25 we're recommending credit for.

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1           Additionally, as Meraj just mentioned, there  
2 was sufficient data to justify allowing credit up to  
3 60 gigawatt-days per MTU assembly-average burnup, and  
4 additionally, ISG-8 Rev 2 had a recommendation that in  
5 order to credit burnup, that cask users should perform  
6 a confirmatory burnup measurement prior to loading, to  
7 prevent a misload.

8           We've evaluated the whole misload issue, and  
9 provided an option in this revision for a misload  
10 analysis, accompanied with additional administrative  
11 loading procedures that may replace that measurement.

12           MEMBER SKILLMAN: Drew, by how much  
13 percentage or by how much hold-down does crediting the  
14 proof of minor actinides and fission products increase  
15 margin of criticality?

16           MR. BARTO: The rule of thumb is that the  
17 major actinides that we previously recommended credit  
18 for, represented about 75 percent of the reduction in  
19 k-effective that comes with burnup, and that these  
20 additional minor actinides and fission products  
21 represent about 25 percent.

22           So it doesn't sound like a lot, but if you  
23 look at how it moves your loading curve, it basically  
24 takes you from being able to load about somewhere in  
25 the neighborhood of 25 percent of the discharged fuel

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1 population to more like 75 or 80 percent of the  
2 discharged PWR fuel population. So it's  
3 a significant increase in capacity basically, increase  
4 in the percentage of the discharged fuel population  
5 that you can transport in a high capacity cask.

6 MR. RAHIMI: I want to add something here  
7 that we should bear in mind, that at any time, you can  
8 transport all the fuel. But we're talking about the  
9 fully-loaded high capacity, you know, if you want it.

10 So even with no burnup credits, you know,  
11 you can transport -- at 32 PWR, let's say that's what  
12 you're talking about, getting designs, 32 PWR, 37 PWR  
13 cask, you can always derate a checkerboard pattern.  
14 You can load, you know, any fuel.

15 So what we're talking about, in terms of if  
16 you want to fully load it, that they do need, you  
17 know, burnup credit.

18 MEMBER SKILLMAN: I understand.

19 MR. RAHIMI: Yeah. So I think for the,  
20 especially members of the public, I want to clarify  
21 that, that the -- I mean you can transport really.

22 MEMBER SKILLMAN: All right, thank you.

23 MR. BARTO: I guess an additional note is  
24 the earlier generation of transport casks that Meraj  
25 was talking about earlier still exists, and are used

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1 today, and they are lower capacity, but they can  
2 basically transport just about anything.

3 MR. RAHIMI: Fresh-fuel assumption. That's  
4 what they transport.

5 MR. BARTO: Okay. So getting into, you  
6 know, why we felt we were able to expand -- expand  
7 burnup credit, and this is an abbreviated list,  
8 really, of the work that's been done in the past 10 or  
9 12 years on burnup credit. But these are kind of the  
10 most recent studies that have helped us the most.

11 In 2008, Oak Ridge evaluated a set of French  
12 critical experiment data that's known as the HTC  
13 critical experiment data, and it's critical  
14 experiments that were designed, as much as possible,  
15 to look like the major actinide distribution that  
16 would be present in 37-1/2 gigawatt-day for MTU burned  
17 PWR fuel.

18 So this was valuable, in that it helped us  
19 really validate well criticality predictions for the  
20 major actinides, which I've already mentioned are the  
21 largest component of the reduction k-effective of  
22 burnup.

23 NUREG, the second bullet there, NUREG/CR-  
24 7012 is a summary document of, I think, five other  
25 NUREGs that detail new sets of radiochemical assay

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1 data for validation of the depletion codes.

2 That's part of why we felt we could raise  
3 the burnup limit up to 60, is that there's a great  
4 deal more high burnup data than was available in 2002.

5 Then the last two bullets there are two  
6 studies that were done by Oak Ridge National Lab, that  
7 are really pretty heavily referenced in the ISG. The  
8 first one develops an approach for -- actually several  
9 approaches for depletion code validation, and then  
10 actually provides some reference bias numbers that can  
11 be used directly by the applicant, and I'll get into  
12 how that's applied a little bit later.

13 Then the last one there, 7109, is an  
14 approach for criticality validation for burnup credit,  
15 and this report also provides reference bias number  
16 that can be used by applicants.

17 MR. RAHIMI: I want to add something here,  
18 and I think that I forgot to mention one of the really  
19 big change that it is, in my opinion, very beneficial  
20 to the industry.

21 Now we have provided an option that we have  
22 calculated the bias uncertainty. They don't have to  
23 do all the rigorous benchmarking. If they use the  
24 same code, the same cross-section single code that can  
25 take the number. I mean that's what is involved.

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1           So I mean that's really a major change from  
2 the previous revisions that makes it much easier.

3           MR. BARTO: And I can follow up on that, in  
4 that we've already approved, I believe three burnup  
5 permit applications. I guess just off the top of my  
6 head, we're probably averaging 40 for review. They've  
7 all -- all of them have been different.

8           All of them have been beyond our Revision 2  
9 guidance in some respect, and it's been quite a bit of  
10 back and forth with the various applicants on what's  
11 acceptable.

12           So we're anticipating that this revision  
13 will make a good deal of that back and forth, at least  
14 about the validation part, will make that go away.

15           So with respect to code validation in ISG-8  
16 Revision 3, we felt that the availability of the high  
17 quality actinide critical experiment data that we were  
18 able to obtain from the French gives a greater degree  
19 of confidence in the actinide criticality validation  
20 than was previously available.

21           Additionally, there's new sets of chemical  
22 assay data that expanded the available database for,  
23 particularly for fission products, for depletion code  
24 validation, and also extended the burnup range.

25           So all of this new data was folded into

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1 NUREG/CR 7108 and 7109, where Oak Ridge developed some  
2 alternative isotopic depletion and criticality code  
3 validation methodologies, wherein the applicants can  
4 either use those methodologies themselves or can use  
5 the reference values, and I'll discuss in a little bit  
6 how that can be done.

7           So for validation, Revision 3 recommended  
8 crediting both actinides and fission products up to 60  
9 gigawatt days for MTU. John Wagner from Oak Ridge is  
10 going to go into a lot more detail about these  
11 particular reports. But we did coordinate with NRR  
12 and NRO on this, which is kind of new.

13           The criticality safety components of the  
14 agency, up until about five years ago, did not really  
15 talk to each other that much. So there were some  
16 disparate methodologies used for kind of similar  
17 analyses in the agency and, you know, since about  
18 2005-2006, we've tried to coordinate a lot more.

19           We've actually started a criticality safety  
20 technical advisory group that's agency-wide now, and  
21 we meet quarterly. So there's a lot more  
22 communication, and hopefully in the future we'll see  
23 a lot more coordination on these types of research  
24 efforts.

25           But just to reiterate, these two reports

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1 develop new isotopic depletion code methodologies and  
2 reference bias and bias uncertainty values.

3 There's also new minor actinide and fission  
4 product criticality code validation methodologies, as  
5 well as referenced bias values, and these reports  
6 provide recommendations on how to use the referenced  
7 values, and how one would use the methodologies to  
8 develop those values.

9 So the ISG basically references these two  
10 reports, and states that applicants can use the  
11 reference bias and bias uncertainty numbers developed  
12 by Oak Ridge, without performing explicit validation,  
13 provided they use the same code and cross-section data  
14 that were used in the Oak Ridge analyses.

15 It's very important that they do that,  
16 because everything that's done in the Oak Ridge  
17 reports points to the fact that these biases and bias  
18 uncertainties are really driven by errors in the data,  
19 at least for criticality. On the depletion side, it's  
20 somewhat driven by the uncertainties in the actual  
21 experimental measurements themselves.

22 MEMBER SKILLMAN: Do all licensees have  
23 access to these codes and cross-section data?

24 MR. BARTO: The codes, the only code system  
25 that was used in these NUREG reports to develop these

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1 numbers was the SCALE code system, you know, primarily  
2 because that's the code system developed by Oak Ridge  
3 National Lab. But also some of the methodologies are  
4 -- the SCALE code system is geared -- there are  
5 components of the code system that are ideal for  
6 performing these sorts of analyses that aren't  
7 available on other code systems.

8 But we believe we have it worked out in the  
9 ISG, to where you're not limited to using the SCALE  
10 code system, and you may use other codes. For  
11 criticality, we're primarily talking about MCNP as for  
12 another code. It's very important that they use the  
13 same cross-section data. So you couldn't come in with  
14 a code, a European code that uses the JEF or JENDL  
15 cross-section libraries, because these reference bias  
16 and bias uncertainty numbers wouldn't, aren't  
17 applicable.

18 MEMBER SKILLMAN: Is there an upper limit on  
19 enrichment, for which these analyses are valid? For  
20 instance, licensees that went to 24-month fuel cycles,  
21 applied for a license amendment and received it for  
22 five weight percent fuel. I see in the write-up the  
23 span of data is between 4.6, I mean 2.453 and 4.657  
24 weight percent 235.

25 So if an applicant has five weight percent

1 fuel as part of its discharge batches, are those  
2 covered by these analyses?

3 MR. BARTO: We believe they are. ISG states  
4 that the upper limit on the applicability is five  
5 weight percent.

6 MEMBER SKILLMAN: Is five weight percent?  
7 Thank you.

8 MR. RAHIMI: Yeah, and also, just to  
9 complete the answer to your first question yes, this  
10 SCALE code is widely available. Any vendor that needs  
11 it, they can call the Radiation Shielding Information  
12 Center at Oak Ridge and they can send them, you know,  
13 the code.

14 So it's widely available actually, you know.  
15 Most everybody, even overseas, you know, other  
16 countries, you know, they call in to get the code.

17 MEMBER SKILLMAN: Thank you.

18 MR. BARTO: And as far as the depletion  
19 validation data, let me back up a little bit here, the  
20 second bullet there, NUREG/CR 7012, like I mentioned,  
21 that's a summary document. There's five other NUREGs  
22 that feed into that document, that in each detail a  
23 set or a group of sets of radiochemical assay data.

24 They're described in pretty good detail.  
25 There should be enough information in those reports to

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1 be able to model those chemical assay measurements.

2 MEMBER SKILLMAN: Okay, thank you.

3 MR. BARTO: So again, very important that  
4 the applicant use the same code and cross-section  
5 data, as was used in the Oak Ridge report, in order to  
6 use the reference bias and bias uncertainty numbers.

7 It's also one of the criterias that the  
8 applicant's storage or transportation system is  
9 demonstrated to be similar to that evaluated in the  
10 NUREG/CRs. There's a number of ways they can do that.  
11 There's sort of a standard way that critical  
12 experiments are compared, through a number of  
13 criteria.

14 Materials, geometry, some physics parameters  
15 like EALF and things like that. But there's also  
16 sensitivity uncertainty analysis that is able to  
17 compare systems, and the system that was used in the  
18 Oak Ridge reports is sort of a theoretical cask  
19 system.

20 It's known as the GBC-32, and it's set up  
21 to look like the kind of high capacity casks that  
22 we're seeing in our applications. So we don't expect  
23 that they'll be anything widely different from the  
24 theoretical cask system. So it ought to be relatively  
25 simple for an applicant to demonstrate similarity.

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1           And then the other key criteria for using  
2 these reference values is that the applicant still  
3 performs traditional criticality code validation for  
4 the major actinides, using the data that is available.

5           The HTC data, the French actinide critical  
6 experiment data has been demonstrated to be very  
7 applicable to validate criticality validation for  
8 major actinides.

9           CHAIR RYAN: Forgive me for asking this  
10 question for you, but have you done any comparisons  
11 or results comparisons with other countries other than  
12 France, other folks that have used the same tools?

13           MR. BARTO: It's, these methodologies are  
14 relatively new. Actually they're kind of completely  
15 new in the NUREGs. So we have sort of tentative plans  
16 to communicate with the international community, to  
17 see if we can't get them to do similar analyses. It's  
18 nothing that's been discussed with anyone, because  
19 it's a tentative plan.

20           CHAIR RYAN: I'm just curious. It's clearly  
21 been a good coordination with the French program. I  
22 just was curious if it has gone beyond that or not at  
23 this point. Thanks.

24           MR. BARTO: So in summary for code  
25 validation, it's often helpful to think about code

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1 validation for burnup credit in four parts. You can  
2 divide it into validation for the major actinides, and  
3 also for the minor actinides and fission products, and  
4 it needs to be done for the criticality analysis and  
5 also for the isotopic depletion analysis.

6 So in the, I guess upper left, for the major  
7 actinides, the criticality validation, this is the,  
8 what I just mentioned, how the applicant can perform  
9 this analysis using applicable fresh UO<sub>2</sub>, MOx and the  
10 HTC experiments, using more or less a traditional  
11 criticality validation approach.

12 For the minor actinides and fission  
13 products, for the criticality validation, the  
14 applicant can use the Oak Ridge-supplied reference  
15 bias number. Then for the isotopic depletion  
16 analysis, for both major actinides and minor actinides  
17 and fission products, applicants have the option of  
18 using the Oak Ridge-supplied bias and bias uncertainty  
19 numbers, or using the Oak Ridge-developed validation  
20 methodologies that are detailed in the NUREG.

21 With respect to burnup measurements that  
22 were recommended in ISG-8 Rev 2, we've had Oak Ridge  
23 do some work on, related to misloads. The first  
24 bullet there, NUREG/CR 6955, was basically a  
25 consequence analysis.

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1           In other words, how much change in k-effect  
2           could you get with a misload, various misloads.  
3           NUREG/CR 6988 was for an overall look at measurement  
4           technologies, what's available to use in, you know,  
5           how do in-pool out of core measurements compare with  
6           in-core measurements, and also a review of, you know,  
7           how in-core measurements are done, versus how the out  
8           of core measurements are done.

9           We also had the Office of Research look into  
10          probability of a misload in a spent fuel cask, and  
11          Brian Wagner from Research is going to talk about that  
12          in a moment.

13          So we've collected all this information on  
14          misloads, and we've determined that a misload is a  
15          credible event that must be considered. However, we  
16          believed it was appropriate to allow an alternative to  
17          the measurement, which is basically performing a  
18          misload analysis to demonstrate that your system is  
19          not overly sensitive to a misload, and then also to  
20          have additional administrative loading procedures that  
21          are geared towards preventing misloads.

22          So the ISG has a number of recommendations  
23          for how to perform a misload analysis. We recommend  
24          that applicants look at a single severely underburned  
25          fuel assembly misloaded into the worse location, and

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1 this misload should be chosen such that the reactivity  
2 of the fuel bounds 95 percent of the underburned fuel  
3 population with 95 percent confidence.

4 I've got a graphic on the next slide that  
5 will kind of show where that is, and based on the  
6 misload events that we've seen so far, the majority of  
7 them have been multiple assemblies, not just a single  
8 assembly.

9 So we recommend that a misload analysis be  
10 performed that also looks at multiple moderately  
11 underburned fuel assemblies, and the criteria that we  
12 recommend for that is that half the cask is filled  
13 with a fuel assembly that bounds the reactivity of 90  
14 percent of the total discharge fuel population, and  
15 this will be more clear on the next slide, when we  
16 show the graphic.

17 There's also, we recommend a reduced  
18 administrative margin for this analysis. The  
19 criticality administrative margin is typically .05 for  
20 a criticality analysis. But we consider the misload  
21 to be sort of an upset condition, and we are -- the  
22 administrative margin can go as low as .02 for this  
23 analysis, and that's consistent with upset conditions  
24 that we've looked at in other regulated areas for  
25 criticality safety.

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1           And again, we recommend a set of additional  
2 administrative loading procedures that I'll talk about  
3 a little more. We got a lot of industry comment on  
4 our proposed procedures, and just a sampling of them  
5 here, ensuring that there's no fresh fuel in pool at  
6 time of loading, since our misload --

7           The misload analysis that we recommend  
8 doesn't include fresh fuel, or and also independent  
9 third party reviews of cask loading. Again, that's  
10 just a handful of -- we've recommended, I believe,  
11 seven in the ISG. That's not intended to be an all-  
12 inclusive list, but I'll go through that in a little  
13 more detail later.

14           MEMBER SKILLMAN: Drew, on your second  
15 bullet there, you said that when you looked at this,  
16 the bulk of the misloads were moderately underburned.  
17 Is that a large population of events or a small  
18 population of events?

19           MR. BARTO: It's a small population of  
20 events, but as we'll see in Brian's presentation,  
21 there's a small population of casks that have been  
22 loaded. So it doesn't take many misloaded casks to  
23 get you into credible space.

24           Now an important point about the misload  
25 events is that no storage casks are being loaded right

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1 now under the burnup credit assumption. So the  
2 misload events that we've looked at are misloads with  
3 respect to other criteria.

4 So there's really no data on or we didn't  
5 glean any information about how they might be  
6 misloaded with respect to a, you know, maximum, a  
7 minimum burnup requirement. You know typically, we're  
8 talking about maximum burnup requirements now for the  
9 radiation heat transfer.

10 So the misload events that we've seen have  
11 failed those criteria, and there's really not  
12 information about, you know, if they come in on the  
13 low side, which is what you're concerned about,  
14 criticality safety.

15 MEMBER SKILLMAN: Thank you.

16 MR. BARTO: So this is just sort of a visual  
17 of the recommended misload analysis criteria. This  
18 sort of cloud of numbers in the background there  
19 represents the entire discharged, entire permanently  
20 discharged PWR fuel population as of 2002, which is  
21 the last time DOE collected complete data on  
22 discharged fuel.

23 The green line represents what you might  
24 expect to get with a loading curve for a cask system.  
25 The blue line is a representation of where you might

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1 expect 90 percent of the total population, a  
2 reactivity that bounds 90 percent of the total  
3 population.

4 The red line is, represents a reactivity  
5 that we would expect that would bound 95 percent of  
6 the underburned population. So you know, there are  
7 handful. If you look at the graph there, you know,  
8 this is actual data, actual permanently discharged  
9 fuel, and there are a handful of assemblies that are  
10 below that line.

11 But we have, we've recommended some  
12 procedures that we think will prevent, you know, any  
13 kind of --

14 CHAIR RYAN: There's nine of them below the  
15 red line.

16 MR. BARTO: What's that?

17 CHAIR RYAN: There's nine below the red  
18 line.

19 (Simultaneous speaking.)

20 MR. BARTO: Probably nine boxes, but there's  
21 multiple assemblies in each box.

22 MEMBER SKILLMAN: Okay.

23 MEMBER ARMIJO: Each number represents the  
24 number of assemblies in that burnup enrichment box.

25 MR. BARTO: Yes, the number of assemblies.

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1 (Simultaneous speaking.)

2 MEMBER ARMIJO: Oh I see, okay. So those  
3 would be ones that we're worried about.

4 MEMBER ARMIJO: You'd worry about --

5 CHAIR RYAN: Yeah. I mean you really have  
6 to make sure those were isolated from the rest of the  
7 population.

8 MR. BARTO: Right, and one of the  
9 recommended procedures that we have is that if you  
10 have these assemblies in your pool, you identify where  
11 they are and, you know, after you load, you'd go back  
12 and make sure that they're still there.

13 It's important. You know, if you actually  
14 go and look at this data, you'll find more often than  
15 not if you see a grouping of assemblies like this,  
16 they're all from one plant. So you know, certain  
17 utilities may be able to make the argument, you know,  
18 I don't have any -- I just don't, I've never  
19 discharged a fuel assembly that's that low for burnup.

20 MEMBER SKILLMAN: The appearance of the even  
21 number in each of those cells in the lower right-hand  
22 corner suggests that it might even be test assemblies  
23 or very, very fresh fuel assemblies --

24 MR. BARTO: Right.

25 MEMBER SKILLMAN: --that had some mechanical

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1 or other failure. Hence, they're discharged right  
2 into the box.

3 MR. BARTO: Yeah.

4 MEMBER SKILLMAN: And so they're very  
5 underburned and very reactive.

6 MR. BARTO: And I haven't looked at those  
7 specific boxes down there, but we have looked at some  
8 of the, some of the boxes that are higher up, that  
9 might even be into the yellow range, and just almost  
10 every time you look at one of those, it's either  
11 entirely from one utility or from one unit, or  
12 possibly from two different units.

13 But it's usually limited to where they're  
14 from, because the practice now is, at least from what  
15 I understand about how fuel assemblies are used, it's  
16 not an ideal situation to discharge a fuel assembly at  
17 that high of an enrichment, and to never put it back  
18 in the core.

19 If it comes out because it's damaged, it's  
20 now usually trying to reconfigure it, to get it back  
21 into the core. So I sort of, without having actually  
22 looked at this specific data that's below that red  
23 line, I would suspect that that's fairly old.

24 MR. RAHIMI: Yeah. Some of those  
25 assemblies, actually I looked at them many years ago.

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1 It was, you know, of the stainless steel variety, you  
2 know, the older version, that really they didn't do  
3 well and they had to be discharged. I believe Yankee  
4 Rowe, you know, made some of those assemblies. As you  
5 said, it was from earlier assemblies that --

6 MR. BARTO: So this -- I believe DOE is  
7 gearing up to do this survey again, and I think if  
8 you, again, I can only speculate. But I would  
9 anticipate that you will see much more growth into the  
10 high burnup range at the higher enrichment, and I  
11 would doubt that you're going to say many, if any at  
12 all, in that little corner there.

13 MEMBER ARMIJO: Does each utility have, each  
14 plant have this curve that's unique to their specific  
15 plant?

16 MR. BARTO: There's a curve that's unique to  
17 the cask design. But you could do this for each  
18 utility essentially. You could --

19 MEMBER ARMIJO: They have the data. They  
20 just have to put it together.

21 MR. BARTO: Yeah, right.

22 MR. RAHIMI: The lines that you see, for  
23 example, the green line, this is for the cask, GBC-32  
24 cask. Depending on the cask, that loading curve, you  
25 know, falls into fuel population. I mean the fuel

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1 population you see, that's the entire inventory in the  
2 pool right now, I mean, as of 2002.

3 CHAIR RYAN: So getting back to maybe  
4 something Drew said earlier, let's say each plant did  
5 have their own, you know, data on this block. They  
6 could then come up with a risk for misload test at  
7 their plant, is that right?

8 MR. RAHIMI: That is true, that is true,  
9 that if each plant, they say okay, this is the  
10 population in my pool, and this particular cask is  
11 coming for shipment. This is the loading curve for  
12 this cast, superimpose it on the population, and yes,  
13 they could, you know, identify the ones that are  
14 below the loading curve.

15 CHAIR RYAN: I may be off base, but it seems  
16 like that would be very helpful information for a  
17 plant to evaluate.

18 MR. RAHIMI: But of course, you know, the  
19 certificate that we issue for the cask is not -- it  
20 could be used anywhere, at any plant.

21 CHAIR RYAN: No, no. I understand that, but  
22 I think that implementing that particular plant, you  
23 know, it's particular to their fuel pool and what's in  
24 it; right?

25 MR. RAHIMI: Yeah, yeah, yeah.

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1 CHAIR RYAN: It seems like there's a --

2 MR. RAHIMI: Actually we did this -- we  
3 approved TN40, which was right now there's currently  
4 a bunch of TN40 casks in storage, in fact for Prairie  
5 Island.

6 They came in, they made a transport  
7 certificate request, and the way they did the misload  
8 analysis, I mean before we developed these criteria to  
9 their pool, Prairie Island pool, we put the TN40  
10 loading curve on that. Based on that, what you just  
11 said, I mean we have them to do misload analysis.

12 CHAIR RYAN: So that way it would be a big  
13 campaign of some sort to remove fuel, or pull it out?  
14 That's when that would get done.

15 MR. RAHIMI: Yeah.

16 CHAIR RYAN: So they're going to probably do  
17 that as a matter of course anyway, or is that a  
18 requirement that they do a misload analysis?

19 MR. RAHIMI: Right now, it is the  
20 recommendation in the ISG, that you need to do a  
21 misload analysis. It is a recommendation, and in  
22 there, applicant is free to come with a different  
23 proposal.

24 CHAIR RYAN: Okay, fair enough.

25 MEMBER ARMIJO: I just want to make sure I

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1 understand this curve. Let's say in your plant you  
2 had all of your fuel had a burnup enrichment -- had  
3 burnup enrichment values that were above, let's say,  
4 the blue line along this curve.

5 MR. RAHIMI: Uh-huh.

6 MEMBER ARMIJO: And you could prove that.  
7 NRC was satisfied that that was actually accurate.  
8 Would a burnup -- would a misload analysis be required  
9 in that situation?

10 MR. BARTO: I think for a, you know, if a  
11 specific utility came in for a, I guess site-specific  
12 transport certificate, we would certainly accept that  
13 without a misload analysis. If they could demonstrate  
14 again that they've never discharged fuel event with  
15 low burnup.

16 (Simultaneous speaking.)

17 MR. BARTO: So, you know, we would certainly  
18 consider that.

19 MEMBER ARMIJO: Great, thank you.

20 MR. BARTO: Okay. We've gotten a little bit  
21 behind schedule. I'm going to let Brian talk a little  
22 bit more about misloads and particular misload  
23 probabilities.

24 MR. WAGNER: Brian Wagner, NRC Research for  
25 the general risk analysis. So in our report we did

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1 three things. We reviewed actual cask misload events  
2 to determine underlying causes, and to identify common  
3 failure modes and see what insights could be gained  
4 from them.

5 The main purpose was to calculate the  
6 probability of one or more casks being misloaded, and  
7 we did that using two separate methods. First, we  
8 just looked at the empirical data and calculated it.

9 Second, we used an event tree model to model  
10 the process for loading a cask, and tried to  
11 theoretically calculate the probability of misload.  
12 That was done to give us additional insights.

13 And finally, we considered the impacts that  
14 burnup would have on the probability of an assembly  
15 being misloaded, and we basically concluded that the  
16 burnup of an assembly isn't likely to affect the  
17 probability that the assembly would be misloaded, with  
18 a few exceptions like for fresh fuel assemblies, which  
19 are visually different from other casks, I'm sorry,  
20 from other assembly.

21 And that if an assembly is misloaded, that  
22 its burnup -- that it will be basically be chosen at  
23 random from the spent fuel population.

24 MEMBER POWERS: Why did you make that random  
25 assumption?

1 MR. WAGNER: Looking at the empirical data,  
2 we didn't see really any pattern, and you know,  
3 couldn't really think of a mechanism for what would  
4 cause a correlation for the burnup of the assemblies  
5 being misloaded. So generally --

6 MEMBER POWERS: I think -- it seems to me  
7 that the potential for correlation of misloads is  
8 extremely high, because if you develop one in the  
9 selection of assemblies, and you bring it through  
10 sequence, then every single one of them after that  
11 would be in error.

12 MR. WAGNER: Yes. Certainly the correlation  
13 for assemblies being misloaded is high. But as far as  
14 the --

15 MEMBER POWERS: Well, you're saying --  
16 (Simultaneous speaking.)

17 MEMBER POWERS: --is uncorrelated. It's  
18 completely random. But once you get off --

19 MR. WAGNER: Then you're off.

20 MEMBER POWERS: Then you're off, right.

21 MR. WAGNER: Right, yeah.

22 MEMBER POWERS: Okay, I agree.

23 MR. BARTO: I'd like just to point out that  
24 you've got to think about it looking at the  
25 population. If you have a misload, you're more or

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1 less selecting from this pot of discharged fuel, and  
2 it would be a smaller pop if you're looking at a  
3 specific site.

4 But the idea is that you will look at the  
5 misload events that have happened, and I'll just let  
6 Brian talk about those a little bit more. But it's  
7 more or less kind of a loss of control of the  
8 assemblies that you're selecting. So I think what  
9 Research found is that you're more or less selecting  
10 at random from this pot of fuel assemblies.

11 MR. RAHIMI: Right, I mean 20 gigawatt-days  
12 versus, you know, 15 gigawatt-days. So the  
13 probability of misloading 20 gigawatt-days, if they're  
14 both underburned. So there is no correlation. So you  
15 could pick any of the underburned fuel.

16 MR. WAGNER: And it's certainly possible to  
17 imagine situations, I guess, where there maybe could  
18 be a correlation. But it's hard enough to predict  
19 what that would be, that you all just have assume that  
20 it's going to be random.

21 So we identified seven misload events and  
22 one-year misload event. I wasn't going to go through  
23 the details of each of them individually. But all of  
24 them stem from errors in the initial planning process,  
25 or the procedures used to load the cask, and they all

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1 involved multiple assemblies and multiple casks. So  
2 I have some of the numbers listed there.

3 One error in particular actually led to  
4 casks at different sites owned by the same licensee  
5 being misloaded. All events were discovered after all  
6 the standard reviews had been done, sometimes years  
7 later and after the casks had been sealed.

8 We included the near-misload event, just  
9 because it's the only example we had of a single  
10 assembly almost being misloaded. So we wanted to  
11 include that, just to show what mechanism could lead  
12 to assembly misload.

13 MEMBER ARMIJO: Yeah. That is what I always  
14 envisioned was the issue, in that someone intended to  
15 pick up this assembly, but it somehow picked up the  
16 wrong assembly. What you point out here is there's  
17 systems in identifying what needs to be opened, and  
18 errors in those systems, at least more prevalent than  
19 just an isolated wdo;l;sdkf9:21.

20 MR. WAGNER: Right. That was surprising to  
21 us too.

22 MEMBER ARMIJO: That to me is one disturbing  
23 event, somebody misreading a serial number marking on  
24 an assembly.

25 CHAIR RYAN: Are these four examples, or are

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1 these, is this the whole population of misloads?

2 MR. WAGNER: This is the whole population of  
3 what we identified. As Drew mentioned, well as he at  
4 least alluded to, these are the ones that were  
5 eventually caught so far. So presumably there could  
6 be more, and there's also an issue of reporting  
7 requirements.

8 If, you know, there's what we might consider  
9 a misload that still satisfies the requirements, then  
10 it wouldn't necessary be reported to us.

11 MR. RAHIMI: Yeah. If they haven't violated  
12 a tech spec, you know, or anything they don't report.  
13 But these are the ones that involve specifically  
14 casks. I mean you've got misload in the pool, you  
15 know, the racks. We haven't even included all those  
16 misload events.

17 CHAIR RYAN: Okay. Yeah, just the casks.  
18 All right.

19 MR. WAGNER: Just the casks.

20 CHAIR RYAN: Okay.

21 MR. WAGNER: And I'll also make the point  
22 now that one of the events seemed to actually be  
23 caused by the fact that the requirements were  
24 complicated.

25 CHAIR RYAN: It's interesting to think

1       though for a second that if you have a misloading in  
2       a pool, like if say one position in the pool as  
3       opposed to some other way and that error is brought  
4       forward, then you could be thinking that a cask  
5       loading is just terrific, and it's not.

6               MR. WAGNER:  It's not, yeah.

7               CHAIR RYAN:  So I would think you'd want to  
8       pull that string a little harder, and go back to look  
9       at misloads in fuel pools, to see what that population  
10       looks like.

11              MR. RAHIMI:  Yeah, we're going to -- I mean  
12       we did look at actually some INPO reports.  We even  
13       looked at that.  But we focused on the casks, since --

14              CHAIR RYAN:  I understand that.

15                       (Simultaneous speaking.)

16              CHAIR RYAN:  I think that should be on your  
17       homework list, to think about is there something  
18       there that needs to be further evaluated.

19              MR. WAGNER:  We'll talk about that a little  
20       bit.

21              CHAIR RYAN:  Okay, and Jack, do you have a  
22       question?

23              MEMBER SIEBER:  That's all based on the  
24       serial number and a misload some place along the line.

25              MR. WAGNER:  Right.

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1 MEMBER SIEBER: If it's possible to catch  
2 that because of the serial number on the fuel --

3 MR. WAGNER: Right. Our understanding is  
4 generally they're checking the actual serial number as  
5 they're loading the casks --

6 CHAIR RYAN: And that's kind of the  
7 backstop, you know, against which those, what's called  
8 misallocation in a pool can be overcome. But I think  
9 it's helpful to pursue that, just to see what is that  
10 population, how big is that?

11 Is it real small or is it prevalent, you  
12 know. That gives you some idea of the intensity with  
13 which we should continue to look at serial numbers if  
14 it's a bigger number.

15 MR. WAGNER: Right.

16 MEMBER SIEBER: And mispositioning in the  
17 pool is sort of a setup for an error when they're --

18 CHAIR RYAN: Exactly, that's my point.

19 MEMBER SIEBER: And some of the serial  
20 numbers are hard to read, you know, quite hard.

21 MR. WAGNER: Yes. I think Drew will talk  
22 about it. I think some of the recommendations get at  
23 that point. So the probability they'll end up with  
24 this is 20 casks misloaded out of 1,200 that have been  
25 loaded. I think that's as of the end of 2009, which

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1 gives you on the order of 10 to the negative 2 per  
2 cask.

3 MEMBER POWERS: Which is kind of the human  
4 error rate for everything known to man, right?

5 MR. WAGNER: Right. All right. So for the  
6 second method, to develop the event tree model, we  
7 modeled the process for loading a cask at a high  
8 level. So the first major step is choosing what  
9 assemblies you're going to load in the cask, and as  
10 we've been discussing, that's a complicated step.

11 There's lots of requirements that go into  
12 that, and you have to satisfy all of them. Next, you  
13 make a fuel move sheet, which contains the serial  
14 numbers, allocations of the assemblies that we move  
15 from the spent fuel pool to the cask, and that's the  
16 sheet that's actually used by the crane operator to do  
17 the moving. The next step is actually transporting --

18 MEMBER ARMIJO: Brian, before you go  
19 forward, of the four examples shown on your Slide 17,  
20 the errors are really in that first layer, that first  
21 level, choosing the assemblies and creating the fuel  
22 move sheets.

23 MR. WAGNER: Yes.

24 MEMBER ARMIJO: So that's a misplanning  
25 error, rather than a mishandling of the fuel.

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1 MR. WAGNER: Absolutely.

2 MEMBER ARMIJO: I think you should start  
3 thinking there's a problem working there, that's more  
4 significant than somebody just basically picking one  
5 assembly in error.

6 Even though the fuel sheet's told him to  
7 pick another one, he just -- it just seems to me  
8 there's a bigger problem working down there in the  
9 planning of these loadings, and verification that  
10 you're doing the pool time calculation right or the  
11 -- your database is solid.

12 It just seems to me that that's most of your  
13 errors are in that, yeah, that category, and not  
14 really simple misloads. It just see misloads as a  
15 mechanical thing, picking up the wrong thing and  
16 putting it in, even though the planning was good.

17 But you're showing us that in these, most of  
18 these examples, planning before is a problem.

19 CHAIR RYAN: Is that a fair comment? I mean  
20 in your view the planning is really the root cause of  
21 this?

22 MR. WAGNER: There's a lot of requirements,  
23 and if you don't satisfy any one of them, then it's  
24 misload.

25 MEMBER ARMIJO: You call it a misload, but

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1 --

2 MR. WAGNER: Yes.

3 MEMBER ARMIJO: For example, on Palisades,  
4 it was a cooling tent, so it was misloaded because it  
5 wasn't using a heat requirement.

6 MR. WAGNER: Right.

7 MEMBER ARMIJO: But it wasn't necessarily  
8 misloaded from a burnup or a criticality issue?

9 MR. RAHIMI: That's correct, yes, yeah. And  
10 yeah, to go back to again, Dr. Armijo's, you know,  
11 argument, that it's true. When you look at it's most  
12 of the events happening on the planning phase, for  
13 example. Some example, you go into the details what  
14 exactly happens, you know, the indexing, for example.

15 A crew, refueling crew, you know, they work  
16 together. They were used to some indexing. They  
17 skipped some letters, and the new crew came in and  
18 that was the error, you know, the indexing. When you  
19 really read about details of these events, then it's  
20 mostly in the planning and identifying, you know.

21 If you give the right information, you know,  
22 if the fuel had a leak and most of the time pick up  
23 the right --

24 (Simultaneous speaking.)

25 CHAIR RYAN: Is there any way of taking a

1 hard look at -- what are the events that caused the  
2 error, they mislaid something. But if it's a planning  
3 error, it seems to me that it's something systematic  
4 that's gone wrong. If all these errors are in one bin  
5 or the bulk of them, who's pulling that string, to see  
6 what really is the root cause.

7 I mean what you describe is not necessarily  
8 the root cause. It's the root cause for the next  
9 thing down the road, what caused that to begin with.  
10 Is there a corrective action that's needed there or  
11 some new process or proof process or something of that  
12 sort? Have you taken a homework assignment for that  
13 target?

14 MR. BARTO: Well I think, you know, we  
15 certainly can pull that string more. But I think in  
16 looking at these events and getting the probability  
17 analysis from Research, that's pretty much what led us  
18 to the misload analysis.

19 CHAIR RYAN: Yeah.

20 MR. BARTO: We're basically concluded that  
21 they're going to happen, and from a criticality safety  
22 perspective, we believe that the better way to deal  
23 with it is simply to show that your cask isn't going  
24 to have a criticality issue, even if you have one.

25 CHAIR RYAN: Yeah.

1 MR. WAGNER: And I should mention there has  
2 been some HRA work done on --

3 MR. BARTO: There has been.

4 CHAIR RYAN: What work, sorry?

5 MR. WAGNER: There's been some HRA work.

6 MEMBER RAY: Does Appendix B apply? Part  
7 50, Appendix B, does it apply to these activities  
8 you're talking about?

9 MR. RAHIMI: Yes. The loading activity,  
10 yes, yes, because in the loading --

11 MEMBER RAY: It wouldn't necessarily apply.  
12 I'm just asking does it apply.

13 MR. RAHIMI: Yeah, it does apply.

14 MEMBER RAY: Because it ought to then  
15 produce the information Mike is asking for.

16 MR. RAHIMI: Well actually we do have the  
17 information. One of the NUREGs that Drew listed that  
18 Oak Ridge did a few years ago, went through all the  
19 reactor event reports, in terms of a misload even, you  
20 know, on the pool sides.

21 And so we did, you know, look at -- that's  
22 where we started, you know, looking on the reactor  
23 side in the pool, all the misload events, and but what  
24 we wanted for this, for the ISG for casks, we then  
25 focused okay, the misload for casks. Let's focus on

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1 that.

2 CHAIR RYAN: Yeah, but that's kind of  
3 separating the dancer from the dance.

4 MR. RAHIMI: Yeah, but you're actually --

5 CHAIR RYAN: There is a second problem, and  
6 now that your basic situation is, because as you've  
7 just explained, there may be errors in that basic  
8 setup that you don't recognize.

9 MR. RAHIMI: The basic setup, yes.

10 CHAIR RYAN: So you can't separate the  
11 dancer and the dance.

12 MR. RAHIMI: You're right. Yes, we will do  
13 that. We will look into it further on the reactor  
14 side.

15 CHAIR RYAN: So we'll think about it too.  
16 But there may be a recommendation coming out of that  
17 discussion. I think that's something -- that's a  
18 productive moment from the work you've done so far.

19 MEMBER ARMIJO: Yeah. Just for information.  
20 On these events, misload events that you've identified  
21 here, I'm just presuming that these led to some  
22 corrective action programs within the various  
23 utilities and they corrected whatever.

24 Can you verify that that's what would have  
25 happened or did happen? Let's say at Palisades or

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1 North Anna and Grand Gulf, that their process for  
2 identifying what needs to be -- identifying the things  
3 that need to be loaded, that their process is okay,  
4 their database is okay? Because if that's wrong, it's  
5 amazing that you don't have more.

6 MEMBER SKILLMAN: It seems that there should  
7 have been an information bulletin or something, not at  
8 a stunning, attention-getting level, but at a basic  
9 level, telling the licensees hey, you know, there  
10 appear to be some process problems, in actually  
11 loading the cask.

12 It appears that one in a thousand, that they  
13 physically latch onto the wrong assembly. One in a  
14 hundred that there is an error in some part of the  
15 transportation process, whether it was the calculation  
16 of heat load or the symmetry or some other such thing.

17 But I would have thought there would have  
18 been an information bulletin or something like that to  
19 our licensees that would communicate a heads-up.  
20 Looks like you're picking the right assemblies; you  
21 may be using the wrong logic to get those in casks.

22 CHAIR RYAN: That may be a good homework  
23 question to take away for the preparation of the full  
24 Committee meeting, and maybe cover a little bit more  
25 of these other things we've just talked about it about

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1 wanting to pull the string.

2 MR. WAGNER: And I think also this problem,  
3 obviously, isn't unique to casks. We have been  
4 talking with NRR and NRO on this issue. So maybe that  
5 can be part of our homework, is to --

6 CHAIR RYAN: Okay. Great, terrific.

7 (Simultaneous speaking.)

8 MEMBER POWERS: When you do your -- in the  
9 error analysis, did you talk to the ATHEANA folks  
10 about errors of commission and things like that?

11 MR. WAGNER: Not really. It's done a whole  
12 lot of time. Doing the human error analysis, we --  
13 I'll get this in a little more detail. But we use  
14 THERP values, THERP values, techniques for human error  
15 rate prediction.

16 MEMBER POWERS: The problem that comes to  
17 mind is you have a highly structured, lots of checks  
18 and balances, checks in the process setup, lots of  
19 opportunities to catch an error, and you end up with  
20 an error rate that THERP has for everything that's  
21 known to man.

22 And ATHENA is really set up to look at  
23 process, that to identify what's wrong with the  
24 process, and you know, that's what it's designed to  
25 do.

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1           It's, I mean it's god-awfully difficult, but  
2           it's a god-awfully difficult problem, because you've  
3           set up a system here that should be making sure that  
4           you're coming down to an error rate that's extremely  
5           low. But you came down to one that is the same for me  
6           adding up numbers in columns.

7           You know, I will make roughly a big mistake  
8           every time I do one of those that I do, with nobody  
9           checking me. But if you ask both Armijo and I to do  
10          the same thing or him to check my work, you will cut  
11          that in half, and you know, it just strikes me on my  
12          to-do list, not necessarily for a full Committee  
13          meeting, but you know, as long as you're planning to  
14          go into BWR plan as well, and to be re-looking at some  
15          of this stuff, go chat with those plant people, and  
16          see if there's anything they can do for you.

17          And understand that the magnitude of an  
18          effort that it is, that maybe sometimes these efforts  
19          are not worth it, not cost-effective. Sometimes  
20          they're very effective. I mean I think the fire folks  
21          found that a lot, when they take Chadwick for the  
22          ATHEANA folks, and came away saying okay.

23          There are other areas that it's not  
24          worthwhile. It's just a different perspective on how  
25          to work the process, as opposed to, you know, doing

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1 the THERP thing. THERP is really good for  
2 understanding how the operator selects things.

3 But when you've got a process sort of thing,  
4 then you need to go to a ruling, because just to  
5 design a process, it's not so obvious as you might  
6 think it is. It's probably worthwhile chatting with  
7 them a little bit, to see what they know that you  
8 don't know.

9 MR. WAGNER: Right, right, right. So as  
10 we've discussed, there's -- after you transfer the  
11 assemblies, there's a review, but that only reviews  
12 the movement of the assemblies, not what terms you  
13 chose in the first place.

14 Next slide. After a few iterations, this is  
15 the event tree we ended up with. It's pretty much the  
16 same as the process flow diagram, except that there's  
17 an independent review which is sometimes performed.

18 We're a little behind on time, right? So  
19 since we talked about a lot of the takeaways from  
20 this, I'll just go over it really quickly, in that you  
21 can see the sequences where your errors in making the  
22 move sheet or transporting the assembly is, you have  
23 several checks that can catch you for the error, and  
24 actually choosing assemblies.

25 Once you've made that error, there is, you

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1 know, we have a fault tree under that top event, which  
2 has review on it. But once you've made that error,  
3 there's no more checks that can really help.

4 MEMBER ARMIJO: Shouldn't the independent  
5 review be at the point where you're choosing the  
6 assemblies? In the event trees of the examples you  
7 showed us, 64 out of 64 of the misloads were choosing  
8 the wrong assemblies.

9 MR. WAGNER: Right.

10 MEMBER ARMIJO: And so wouldn't your  
11 independent review, shouldn't it focus on the very  
12 beginning of the process, rather than a final end?

13 MR. WAGNER: That would certainly reduce the  
14 probability.

15 MR. BARTO: And that is a recommendation, as  
16 part of our additional administrative loading  
17 procedures, that you have an independent review.

18 MEMBER ARMIJO: Yeah, yeah, because I know  
19 in my mind, I just took it for granted that the front  
20 was really nice and clean and orderly, and that  
21 somewhere out in the plant, somebody just picked up  
22 the wrong assembly for one reason or another. But  
23 that's not the case at all.

24 MR. WAGNER: Right.

25 MEMBER ARMIJO: Yeah.

1 MR. WAGNER: And the way we modeled this is  
2 we modeled errors in choosing assemblies as multiple  
3 misloads, and errors in transferring them as single  
4 misloads, mostly just based off of what we've seen.

5 So we use spent fuel pool data for the  
6 actual transferring of assembly use. There was a  
7 Bechtel report that actually looked at misloads within  
8 the spent fuel pool, and actually came up with a  
9 probability for that. So we used that probability for  
10 the actual transferring of the fuel assemblies, and  
11 THERP numbers for everything else.

12 And as we discussed, the dominant sequence  
13 by far is the multiple misload sequence, that comes  
14 from errors in the initial planning process. Next  
15 slide.

16 So ultimately the conclusion is that  
17 misloads are credible. We see them, they happen, and  
18 they happen from errors in the planning process and  
19 involve multiple assemblies and casks.

20 Once you've made that error in the planning  
21 process, the errors that were seen at some -- you  
22 largely kind of lose control of the whole system, and  
23 many of the assemblies that you're loading are all  
24 just random at that point. So it does seem that they  
25 always cause multiple misloads.

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1 CHAIR RYAN: Well, it's really not random.  
2 It's a sequence of misloads that are created by a  
3 single first error.

4 MR. WAGNER: Right.

5 CHAIR RYAN: It's a consequence of the first  
6 error. It's not random.

7 MR. WAGNER: Well, correct.

8 (Simultaneous speaking.)

9 MR. WAGNER: Well, it's not right. Not  
10 actually the right term.

11 MEMBER ARMIJO: The characteristics of the  
12 misloaded assemblies are more or less random.

13 CHAIR RYAN: Right.

14 MR. WAGNER: Or at least unpredictable.

15 MEMBER ARMIJO: Right.

16 MR. WAGNER: That was intended.

17 CHAIR RYAN: Well theoretically, if you knew  
18 the first failure, the assembly that was misloaded,  
19 you could predict all the rest, because it would  
20 follow. So that's not random.

21 MR. WAGNER: Right, right, right.

22 CHAIR RYAN: That's a direct result of the  
23 first error.

24 MR. WAGNER: Right.

25 CHAIR RYAN: Now that's a big deal. To me,

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1 that's a really big deal, because I mean if you find  
2 the first one, we've prevented a lot of them.

3 MR. WAGNER: Right, that's true.

4 CHAIR RYAN: So I would find the first  
5 error.

6 MR. RAHIMI: Okay. So I guess eventually  
7 the analytical method, 10 to the minus 3. So it came  
8 out in the actual data, compared to the theoretical,  
9 and it was about, you know, one order of magnitude.

10 CHAIR RYAN: Okay, John.

11 DR. WAGNER: My name is John Wagner. I'm a  
12 group leader of Design Safety Assimilation and  
13 Integration Group at Oak Ridge National Laboratory.  
14 I'm going to be talking about burnup credit code  
15 validation. I want to make sure that I say for the  
16 record that the key personnel.

17 There's been a number of folks that worked  
18 on this project; John Scaglione, Don Mueller and B.J.  
19 Marshall on the criticality side; Georgetta Radulescu,  
20 Ian Gauld and Germina Ilas on the depletion validation  
21 side.

22 I have the challenge, a little bit, of  
23 talking about two rather thick NUREG documents, and  
24 try to convey the technical information in them within  
25 20 to 30 minutes. So we'll see how well I do on that.

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1           Rather, before I dive into what's in the  
2           depletion validation NUREG and what's in the  
3           criticality validation NUREG, I want to say a few  
4           words about background and purpose, why these were  
5           done. Some of that probably will be obvious, but I'll  
6           spend at least a couple of minutes on that.

7           What I would like to see is what I've seen  
8           so far, is that ask you questions where things aren't  
9           clear enough. So just quickly on the background, the  
10          most significant challenge to expanded burnup credit,  
11          what I mean by that is additional credit for burnup,  
12          has been the validation of the depletion and  
13          criticality calculations, and in particular the  
14          availability and use of applicable measured data as  
15          was mentioned earlier, and especially for fission  
16          products.

17          Applicants and regulatory reviewers have  
18          been constrained about the paucity of the data, as  
19          well as the lack of clear technical basis or approach  
20          or use of the data. As I think Meraj indicated  
21          earlier, there's been a number of applications for  
22          burnup credit, and I think it's fairly safe to say  
23          that each one took a slightly different approach on  
24          how they used the data that they had to work with, and  
25          how they made their case for their credit for burnup.

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1           Which leads to, you know, protracted review  
2 times for those license applications. So that's  
3 hopefully something that will help with this work.  
4 Just note that it was mentioned already that the  
5 rationale for restricting ISG-8 Revision 2 not only  
6 was based on limitations in the available validation  
7 data at that time.

8           So the purpose, the charge that we took on  
9 with this work is to try to establish technically  
10 sound defensible validation approaches for criticality  
11 safety evaluations, based on the best available data  
12 methods that are available.

13           And so -- and then to, after developing  
14 those methodologies or approaches, to apply those  
15 approaches to representative systems. In particular  
16 we're talking here about storage and transportation  
17 casks. I'll note that in the NUREGs, we also looked  
18 at spent fuel pool application 12.

19           But the focus on everything I'll say here is  
20 PWR storage and transportation casks. But apply those  
21 to those representative systems, and to demonstrate  
22 their usage and applicability, and to provide the  
23 reference results which were referred to earlier, and  
24 I'll show some of those.

25           Then of course obviously we need to document

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1 the approach so that for those folks who are -- or  
2 those potential applicants who do not choose to use  
3 the reference values, that they understand how the  
4 approach is to be implemented and used.

5 So kind of an overview of the depletion  
6 validation approach is in this slide, and so the bias  
7 uncertainty in the predictive fuel isotopic  
8 compositions is developed based on a comparison to  
9 measured isotopic compositions from disruptive  
10 radiochemical assays.

11 For those that are not familiar with what  
12 that is, these are where actual spent fuel pieces are  
13 dissolved, and the individual nuclide concentrations  
14 are measured, okay. So that's a key point, that we  
15 are preparing what we predict the concentration of a  
16 given nuclide could be with our curves, to what has  
17 actually been measured.

18 Then based on that, that gives us a bias and  
19 a bias uncertainty in those compositions. What we'd  
20 really like to know is how do those biases and  
21 uncertainties affect our prediction of k-effective for  
22 our safety analysis models.

23 So we used something called a Monte Carlo  
24 uncertainty sampling method to estimate the bias and  
25 uncertainty in k-effective, due to the bias and

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1 uncertainty in the isotopic compositions. So you can  
2 think about this as sort of propagating that bias and  
3 uncertainty from the compositions to the k-effective  
4 values.

5 We also, there's a few different ways to try  
6 to do validation for the depletion calculations, and  
7 we also did additional analyses using something called  
8 the direct difference method, and sensitivity  
9 uncertainty techniques, to provide additional  
10 confidence in the results we're getting, to evaluate  
11 certain aspects of it and so forth, to basically  
12 increase our confidence in what we were doing.

13 So then using the Monte Carlo sampling  
14 method and the radiochemical assay data, we determined  
15 bias and uncertainty values for representative storage  
16 and transport cask configuration, using SCALE 6.1 and  
17 ENDF/B-VII data, which is the latest available nuclear  
18 data that we have.

19 Then the sort of last thing that we did in  
20 the approach was because we were thinking that we  
21 would like to provide some reference validation values  
22 for applicant to potentially use, we need to  
23 understand how sensitive is our bias and uncertainty  
24 values to the various parameters that might be  
25 different from our system to another system.

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1           So we did, we evaluated the sensitivity of  
2 the bias and uncertainty parameters or values, to  
3 things like enrichment and burnup and boron  
4 concentration in absorber panels and things like that.

5           So we picked about, I want say roughly a  
6 dozen different parameter variations, and then  
7 evaluated the sensitivity of the bias and uncertainty  
8 of those parameter variations.

9           So I have no intention to go through this  
10 table. I provided it really more for information and  
11 for me to make a couple of points. On the PWR side,  
12 we have 100 fuel samples that we used. This number of  
13 fuel samples has expanded in the last, particularly in  
14 the last five years or so.

15           We, Oak Ridge and NRC have been very  
16 involved in international programs, and that's where  
17 some of the more recent and good data has come from.  
18 So we've been very in tune to what's going on in the  
19 international community.

20           The other point I wanted to make on this  
21 slide is this gives you some indication of the area of  
22 applicability of the data, in terms of the assembly  
23 design, enrichment and burnup ranges.

24           This is another cut at the data, and there's  
25 a point I would like to make on this, and that is that

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1 say five to ten years ago, most of the radiochemical  
2 assay data that we had provided measured values for  
3 the principle actinides.

4 So you'll see on the left-hand side the  
5 actinides list a number of samples. There's quite a  
6 significant number of measured sample points for the  
7 primary actinides. And again, that's part of the  
8 reason why ISG-8 Revision 2, you know, recommended  
9 credit for actinides.

10 In recent, at that time, there were a few  
11 samples for some of the relevant fission products.  
12 But over the last ten years, there's been a rather  
13 significant increase in the number of available  
14 samples for the fission products, which now enables us  
15 to actually make use of those samples and provide a  
16 technically defensible validation approach with those  
17 samples.

18 You'll notice that some of them are still  
19 relatively few, and how that gets portrayed into the  
20 methodology is then fewer samples affects your  
21 tolerance factor that is used. So you pay sort of  
22 what I call a penalty, due to the uncertainty, due to  
23 the relatively few number of samples.

24 MEMBER ARMIJO: Yeah. I had a question on  
25 the analysis for fission products, for volatile

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1 fission products like cesium. You know, in these  
2 chemical analyses, is only the fuel particles  
3 dissolved and chemically analyzed, or is there effort  
4 to dissolve what's deposited on the ID of the  
5 cladding? You know, there's quite a bit of cesium  
6 that accumulates there.

7 DR. WAGNER: So this is one of the  
8 challenges with doing radiochemical assays, because  
9 for one thing, this table of data represents data  
10 that's been collected over the course of more than two  
11 decades, and as people have done these measurements,  
12 they've learned how to do things better.

13 And so what we see is that, for example, one  
14 of the reasons that the rhodium sample is relatively  
15 few is that it's not very soluble, and so it can be  
16 difficult to measure. So my point in this is you'll  
17 see cesium hasn't been measured very much. It  
18 certainly wasn't measured in the early, so-called  
19 early days.

20 It's been measured more recently, where  
21 these kinds of issues are more understood. But I  
22 don't want to give you the impression that these  
23 measurement approaches are perfect. There's a lot of  
24 room for uncertainty to creep into these measurements,  
25 in terms of capturing all the material. So I don't

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1 know if that gives you a satisfactory.

2 MEMBER ARMIJO: Yeah. I'm just saying my  
3 guess is if all you did -- let's say if cesium was  
4 really important, the isotope in cesium, you would  
5 under-predict the amount of cesium if you just  
6 measured the fuel particles, the fuel tube, because  
7 quite a bit of cesium is deposited on the ID of the  
8 cladding, particularly for high burnup fuel.

9 And it may or may not be important, but  
10 those volatiles are in there some place, and maybe  
11 they affect criticality, even though you're not  
12 measuring them. They're either on the cladding or in  
13 the fuel there. They're there.

14 DR. WAGNER: Right. So one of the  
15 challenges, I'll reiterate. One of the challenges  
16 with this approach is the accuracy of the measured  
17 samples. So if the measured samples are not accurate,  
18 or they are inaccuracies, then we see a spread in the  
19 comparisons between calculating experiment values that  
20 is due to that.

21 You know, whereas normally you would think  
22 the experimental measurements are perfect and the  
23 calculations are wrong and we're comparing to that.  
24 So we have the combination of these effects, and what  
25 we find is that it manifests itself in terms of a

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1 rather large uncertainty around the bias values.

2 That's part of the reason that we've gone,  
3 I'm getting ahead of myself a little bit, that's part  
4 of the reason we've gone to try and address that  
5 uncertainty in a more realistic manner. Hence this  
6 Monte Carlo uncertainty sampling approach that we've  
7 gone to.

8 MEMBER POWERS: Now I don't understand quite  
9 how you do that.

10 DR. WAGNER: Pardon me?

11 MEMBER POWERS: I don't understand quite how  
12 you do that.

13 DR. WAGNER: How we do what?

14 MEMBER POWERS: The Monte Carlo sampling.

15 DR. WAGNER: I'll get to that.

16 MEMBER POWERS: In the face of systematic  
17 error.

18 DR. WAGNER: You have probably systematic  
19 error in one sample, in set of measurements. But what  
20 we're actually dealing with is a number of sets of  
21 measurements.

22 MEMBER POWERS: Not to what he's talking  
23 about. I mean if you take his example, and what's a  
24 good example? A good example is a pandemic, systemic  
25 error.

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1           Say you have an accumulation of cesium in  
2           the ID of the cladding as you will, every analyst will  
3           make that error and it will be in the scatter, because  
4           the simple matter of that cladding ID material will  
5           adhere to the fuel particle, and that will depend on  
6           how you extract the fuel from the cladding to give you  
7           the dissolution.

8           But it's systematic error. So how do you  
9           pick the distribution that you're going to use for  
10          your Monte Carlo sampling?

11          DR. WAGNER: So one of the things that we  
12          looked -- first of all, regarding the dissolution, the  
13          cladding is put in the acid as well. So --

14          MEMBER ARMIJO: Actually, you slice the  
15          whole fuel rod and you take that sample of cladding  
16          plus fuel, and dissolve it all.

17          DR. WAGNER: Right, right, and obviously the  
18          cladding doesn't dissolve, but the surface things will  
19          dissolve.

20          MEMBER ARMIJO: Right.

21          DR. WAGNER: Actually, things that typically  
22          won't come out of that as well are things where heavy  
23          kind of projectile actinides actually, are embedded in  
24          the deep end. That's a very small effect, but that's  
25          more of the thing that would not get dissolved out,

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1 and it would have to be kind of mechanically taken out  
2 of it. So that's kind of that issue.

3 So the point that you're getting at, I  
4 believe, is are these, is this a -- is the  
5 distribution of the uncertainty, is it a normal  
6 distribution, which would mean it's, you know, it  
7 doesn't have a systematic kind of behavior, or is it  
8 a systematic uncertainty that we have to deal with?

9 And so that's part of where we calculate a  
10 bias, an uncertainty on that bias. We look at the  
11 distribution of that uncertainty around that bias, so  
12 that we can determine how to sample that distribution  
13 in our Monte Carlo uncertainty approach. Should we  
14 use a normal distribution or should we use something  
15 else?

16 MEMBER POWERS: Manifestly it's not normal.

17 DR. WAGNER: Right, right, and so we do --

18 MEMBER POWERS: It could not possibly be  
19 normal.

20 DR. WAGNER: Right. So we do have some  
21 isotopes that were non-normal, and so that --

22 MEMBER POWERS: None of them could be  
23 normal.

24 DR. WAGNER: A fair number of them were  
25 normal.

1 MEMBER POWERS: Never, absolutely could not  
2 be, because the normal distribution goes out to  
3 infinity on both of them, and you never have negative  
4 values.

5 DR. WAGNER: You have normality tests, and  
6 for a fair number of isotopes, they passed the  
7 standard normality test.

8 MEMBER POWERS: Doubt it.

9 (Laughter.)

10 DR. WAGNER: I don't know what else to say  
11 on that. We have the data. I mean I can provide the  
12 data. We can run our favorite normality test and look  
13 at that.

14 MR. RAHIMI: But also I do want to add, if  
15 the question touches on -- I mean Dr. Armijo had a  
16 question on okay, the cesium deposit on the cladding.  
17 If you're just going after the fuel, the cesium in the  
18 fuel, and your question is that is a systematic error.

19 If all the time you're looking at the fuel  
20 you're missing. But normally these samples, you know,  
21 are done at a month elapse, and that's different  
22 techniques each lapse uses, and an average is used.

23 So there's that sort of a combination, one  
24 technique, one lab is not used, you know. I don't  
25 know specifically, John, that the cesium-137, we've

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1 got only seven samples, if those samples were done in  
2 your data or data --

3 (Simultaneous speaking.)

4 MEMBER ARMIJO: Yeah, but you know, I think  
5 they tend to be conservative. The thing I'm raising,  
6 the issue I'm raising is you measure less cesium than  
7 is actually there. It's more from the criticality  
8 standpoint it is there.

9 DR. WAGNER: It is there.

10 MEMBER ARMIJO: And so it's a conservative  
11 error. But I just wondered how it, what actually got  
12 measured, whether it was the entire slice of the fuel  
13 rod at a particular location, including the cladding,  
14 all of it's resolved, and then you do the isotopics.

15 MR. RAHIMI: Yeah, we can look into that.  
16 Yes, we can ask. Dionne is at Oak Ridge. He's the --

17 (Simultaneous speaking.)

18 DR. WAGNER: I mean actually we already  
19 have. We've looked at each laboratory, how the  
20 measurements were done, what their stated  
21 uncertainties are, what we believe their uncertainties  
22 to be based on evaluation of the data. It's all  
23 documented.

24 MR. RAHIMI: But the question is when they  
25 measure the cesium, is it just from the fuel, or is it

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1 from dissolved cladding and cesium? I mean that's the  
2 question.

3 (Simultaneous speaking.)

4 MEMBER ARMIJO: You've got all of it. So  
5 you've got --

6 DR. WAGNER: You can never say whether  
7 you've got all of it. I mean you can't say that for  
8 sure. But certainly the cladding in the fuel was put  
9 in those, and dissolved in the acid together, and then  
10 the cladding is --

11 MEMBER ARMIJO: Then you've got pretty much  
12 all of it.

13 DR. WAGNER: I would think so. We can go  
14 back -- one thing we can do is go back and look at the  
15 C over E value specifically for cesium, for example.

16 MEMBER ARMIJO: --for any of the volatiles,  
17 cesium, iodine, cadmium, those kind of things.

18 DR. WAGNER: You see, iodine you don't  
19 credit because of, you know, because of its  
20 volatility.

21 MEMBER ARMIJO: Okay.

22 DR. WAGNER: Okay.

23 CHAIR RYAN: So we're scheduled for a break,  
24 and I wanted to offer the choice of maybe having a 15  
25 minute break now and having you come back, or do you

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1 want to finish first?

2 DR. WAGNER: I'll leave that to you guys.

3 CHAIR RYAN: So why don't you cover it in a  
4 few minutes? I don't want to, you know, have a break  
5 ten minutes before the break, ten minutes before the  
6 break comes up.

7 DR. WAGNER: Okay.

8 CHAIR RYAN: So my suggestion would be if  
9 this is a good stopping point or break point, we'll  
10 take a 15 minute relief break and come back promptly  
11 at 10:15. Is that fair enough?

12 MR. RAHIMI: Yes, sure.

13 (Whereupon, the above-entitled matter went  
14 off the record at 9:59 a.m. and resumed at 10:13 a.m.)

15 CHAIR RYAN: Dr. Wagner, we left off with  
16 you, please.

17 DR. WAGNER: Okay, all right. Shall I  
18 proceed? So I was talking about the Monte Carlo  
19 uncertainty sampling method. In the interest of time,  
20 I will try to go through this pretty quickly. I've  
21 been told that you all have copies of the reports, and  
22 so --

23 CHAIR RYAN: We do.

24 DR. WAGNER: Bear with me as I try to go  
25 through relatively quickly. I've already mentioned

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1 that this uncertainty sampling method is used to  
2 propagate the isotopic bias uncertainty to k-  
3 effective. It provides a realistic safety margin or  
4 bias uncertainty, because it allows for compensating  
5 positive and negative effects, the distribution of the  
6 sample.

7 It enables depletion code validation  
8 directly on the safety analysis model. This is kind  
9 of in reference to other methods, where you have to --  
10 they can't properly address things like axial or  
11 radial burnup distributions.

12 You apply this method directly on the safety  
13 analysis model that you want to demonstrate a bias  
14 uncertainty for. The other nice aspect of this method  
15 that was a reason for choosing it was that it's not  
16 sensitive to the limited number of nuclides measured  
17 in the individual fuel samples.

18 You say okay, well what does that mean? It  
19 means that one lab may have measured 12 of the  
20 isotopes that we care about. Another lab, another  
21 sample, may have measured 28. So there's  
22 inconsistencies in the number of isotopes of the  
23 different ones measured.

24 Now this doesn't affect this method, because  
25 from that, we can still get a bias and a bias

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1 uncertainty and use it directly. For other methods,  
2 it presents a challenge. So the method is illustrated  
3 schematically in this. I understand this is busy, but  
4 I think it kind of portrays it in one slide how it all  
5 works.

6 You actually do calculations for the  
7 individual radiochemical assay samples to do your best  
8 estimate prediction of the isotopic compositions.  
9 From that, you get a bias. You get a bias and  
10 uncertainty from that for each nuclide.

11 Then for your safety analysis model, you  
12 calculate a nuclide concentration, and you from the  
13 bias uncertainty you sample randomly or according to  
14 the proper distribution, the -- how far off the mean  
15 bias that you are. Then based on this formula, you  
16 adjust your calculated nuclide concentration by the  
17 bias and a representation from the Monte Carlo  
18 sampling of the uncertainty in that bias, which gives  
19 you an adjusted nuclide concentration.

20 You do that for each nuclide within the  
21 model, and then you put those adjusted concentrations  
22 into a k-effective calculation. You calculate k-  
23 effective with those adjusted isotopes, and you repeat  
24 that process for a statistically significant number of  
25 criticality calculations.

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1           For the calculations that we did, we  
2 typically did 500 criticality calculations, to ensure  
3 that we had a reliable mean and a reliable standard  
4 deviation estimate, from which we can calculate bias  
5 and bias uncertainty based on the upper limit for one  
6 side of the tolerance interval for 95 percent of the  
7 population and 95 percent confidence.

8           That's how we get the bias and bias  
9 uncertainty values. Here's some examples of those  
10 bias and bias uncertainty values. Now I should note  
11 that in the cases that we looked at, we found that the  
12 bias actually was positive, meaning that we were over-  
13 predicting k-effective, and you don't take credit for  
14 positive bias in criticality safety applications, just  
15 as a standard practice.

16           So these values, although the bias and bias  
17 uncertainty values together, the bias is zero. So it  
18 really is the bias uncertainty values that result,  
19 because the bias is set to zero.

20           So this shows as a function of burnup the  
21 bias or bias uncertainty values for actinide-only  
22 cases, and for actinide and fission product cases.  
23 You see generally speaking, these numbers vary between  
24 one and a half and three percent in delta k over the  
25 range of five gigawatt-days to 60 gigawatt-days.

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1 These are numbers directly out of the ISG-8 Revision  
2 3.

3 So then from this, we had recommendations  
4 that came out of -- into the ISG. I mean there's a  
5 whole lot of information in these reports, by the way,  
6 so I'm just touching it really. But from those  
7 numbers then, we worked with the NRC and came up with  
8 recommendations on how to use this information.

9 So you're probably all familiar with this,  
10 so I don't need to go to every detail of it. But the  
11 general main points are that there are several  
12 isotopic depletion validation methodologies that are  
13 recommended as applicants can use. That's stated in  
14 the ISG.

15 If they, if an applicant does not wish to go  
16 through that process, and you know, there is a fair  
17 bit of work in that, then they can use the values that  
18 are provided in that NUREG, which are also echoed in  
19 the ISG, provided they meet certain criteria.

20 I think Meraj spoke of this criteria earlier  
21 this morning. The main points being same code and  
22 cross-section library in similar kind of situations to  
23 what was evaluated in the NUREG document. Those  
24 values, by the way, correspond to these listed  
25 actinides and fission products.

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1           So moving on to the criticality validation  
2 side, I'll pause for a minute in case there's  
3 questions on the isotopic. I start out with what's  
4 the challenge on the criticality side?

5           On the isotopic side, it was the number of  
6 data points in measured data and the issues with the  
7 measured data, how to use it. On the criticality  
8 side, the primary issue was that the existing or  
9 available laboratory-critical experiments.

10           These are experiments with fuel that was  
11 taken critical, gives us a reference k-effective,  
12 experimental k-effective value, and then we calculate  
13 k-effective on that configuration with our codes, and  
14 we look at the difference between the two, and that's  
15 how we develop a bias and uncertainty. It's sort of  
16 the traditional approach.

17           A key point in that is that those critical  
18 experiments need to be representative of the system  
19 that you're trying to show that your codes predict  
20 accurately for, so-called applicability of the  
21 critical experiments to your safety application.

22           But the challenge has been that these  
23 laboratory-critical experiments that are available do  
24 not have the minor actinides and fission products in  
25 the proportions that are actually similar to actual

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1 spent nuclear fuel, and hence are not directly used in  
2 a traditional way, cannot be directly used. So that's  
3 been our challenge.

4 Now part of that challenge has been  
5 mitigated, at least for the primary actinides, through  
6 evaluation of the laboratory criticals that do have  
7 uranium and plutonium, identifying which ones are  
8 applicable and actually neutronically similar to spent  
9 fuel, and then the access to the available French HTC  
10 critical experiments that was mentioned earlier.

11 It's a very nice set. There's 156  
12 experiments there, so a very significant number. It  
13 was specifically designed for this purpose.

14 And related to that, there was a question  
15 about us coordinating with the French program. I'd  
16 just note that primarily what we did there is we  
17 purchased access to that data, because they spent  
18 quite a bit of money obviously on those experiments.  
19 So the U.S. purchased access, and have made that data  
20 available to cask licensees.

21 So that remains then the challenge. The  
22 focus has been squarely, and really the focus of this  
23 NUREG is focused squarely on how to validate the  
24 fission products and the minor actinides, where we  
25 simply don't have much in the way of laboratory-

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1 critical experiments.

2 Now we do have some. There are a few  
3 laboratory-critical experiments that include a couple  
4 of the fission products in the international handbook  
5 of criticality benchmarks, and there are -- the French  
6 did a series of fission product criticals as well that  
7 we had access to.

8 So we do have some. So we looked at those.  
9 Then, but again, they're not in the right proportions  
10 and there are issues, and they're relatively few in  
11 the number of samples. So then we kind of stepped  
12 back and looked at okay, how do we move forward in  
13 this area, given that we are not going to get the  
14 perfect fission product experiments?

15 We've been using sensitivity uncertainty  
16 analyses quite a bit at Oak Ridge, and looking at  
17 neutronics similarity and understanding biases. And  
18 through this process, we've also looked at the fact  
19 that a lot of our biases in criticality calculations  
20 or the real source of the bias in our criticality  
21 calculations is errors in nuclear data.

22 And so we looked at using nuclear data  
23 uncertainties to estimate potential biases for given  
24 relevant nuclides, and we have some tools that can do  
25 that. I'll talk about that in a minute.

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1           Then the next question is okay, well you can  
2 do that, but how do you know if it's right or reliable  
3 or directly useful for coming up with a bias for the  
4 fission product? How do you defend that, okay?

5           So what we did there was we tried to verify  
6 these estimated biases to comparisons with cases where  
7 we actually have laboratory-critical experiment data,  
8 and can calculate a bias in a traditional means. So  
9 we're comparing that to what we get from this other  
10 approach.

11           We also compared in that process, including  
12 cases where we do have some limited fission product  
13 criticals. So we compared what we get for a bias from  
14 those with what we predict, based on nuclear data  
15 uncertainties.

16           So I talked a little bit about how we  
17 estimate the bias based on nuclear data uncertainties.  
18 Certainly in a system, k-effective can be propagated  
19 from the cross-section uncertainty through a sensitive  
20 coefficient.

21           So what a sensitivity coefficient is, I mean  
22 I apologize. You can spend a lot of time talking  
23 about this, so I'll try to stay at a high level.  
24 Sensitivity coefficient gives us the sensitivity of k-  
25 effective to change in a cross-section, okay.

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1           Now if we fold that with the uncertainty in  
2 a cross-section, then we get the sensitivity of k to  
3 that uncertainty in that cross-section. So that's  
4 what we're after here, is what's the uncertainty in  
5 the k-effective value due to uncertainties in the  
6 nuclear data, and we can get this on a nuclide by  
7 nuclide basis.

8           Actually, we can get it on a reaction by  
9 reaction basis, if you want it. We're actually  
10 interested in it on a nuclide by nuclide basis.

11           So the fundamental basis for this approach  
12 is, again that I mentioned, is that the biases are  
13 caused by the nuclear data errors. The biases are  
14 caused by other things. This doesn't, you know, we're  
15 not dealing with that. So that's an issue.

16           Now what we've also seen, though, is that  
17 the biases are bounded by the nuclear data  
18 uncertainties. The point I'm trying to make there is  
19 that the key point in this is are the nuclear data  
20 uncertainties accurate. If they're underestimated,  
21 then you could underestimate the bias that you're  
22 predicting from this.

23           And what we've observed over the years is  
24 that the nuclear data uncertainties are actually too  
25 large, all right. So they were overestimating the

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1 bias. But we still wanted to go through and do  
2 comparisons to check that assertion.

3 So that in that last point, uncertainties  
4 give us an upper bound for the magnitude of the bias.  
5 So here's just a couple of examples. We have lots of  
6 them. But here's a couple of them, where we confirm  
7 that the computational bias is generally bounded by  
8 the cross-section uncertainty.

9 So let me explain what these charts mean  
10 quickly. These black dots are actually C over E  
11 ratios for given laboratory-critical experiments, and  
12 each one of the charts represents a set of  
13 experiments. This is not nomenclature I would expect  
14 everybody to know.

15 But for example, this is high enriched  
16 uranium metal fast-spectrum systems, and so on and so  
17 forth. So we looked at classes of systems, and again,  
18 going back to the plots themselves, these black things  
19 are the C over E ratio.

20 So this is the bias that we see on an  
21 individual experiment and our ability to predict it.  
22 The green dots are the experimental uncertainties or  
23 the listed experimental uncertainties, and you know,  
24 as they're estimated, and then the brownish bars  
25 represent the uncertainty in the k-effective that we

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1 predict, based just on the nuclear data uncertainties.

2 So in looking at, you know, literally  
3 hundreds of these, where we do have good laboratory-  
4 critical experiments, we've shown that by using the  
5 cross-section uncertainty, we come up with a larger  
6 value and a consistent value with what we get from the  
7 critical experiments were we have them.

8 That's important, because now we're going to  
9 say that we're going to use those where we don't have  
10 good laboratory-critical experiments, or where we have  
11 laboratory-critical experiments that are inadequate in  
12 various ways.

13 Now in this chart, I'm only showing you  
14 experiments that don't have fission products in there.  
15 We also did do comparisons with cases with like the  
16 French fission product criticals, in the few cases  
17 where we have fission product criticals, and show that  
18 we were getting consistent answers.

19 It wasn't a perfect comparison, because  
20 again that data is so limited in numbers of samples,  
21 that it's in proportion of fission products, that  
22 there's a fair bit of uncertainty in the use of those.

23 So to give you some example, then, of  
24 results, I just have, you know, very kind of high  
25 level numbers here to give you some perspective on

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1 this. So this is for -- these tables are for spent  
2 fuel pool high density rack-type application and the  
3 32 assembly PWR cask model.

4 This table shows you the uncertainty in  
5 terms of percent delta k over k, for different kind of  
6 classes of nuclides. You'll see that for actinides  
7 only, we're showing about a 500 PCM uncertainty due to  
8 nuclear data uncertainties.

9 For those who are familiar with these,  
10 that's actually pretty consistent with the bias we see  
11 for LEU actinide-only types of applications. To put  
12 things in perspective then, now when you look at the  
13 fission products, we're seeing, you know, on the order  
14 of 20 to 50 kind of PCM.

15 So rather small numbers as a result of the  
16 nuclear data uncertainties in the fission products and  
17 the minor actinides, particularly in perspective to  
18 the actinides. It goes back to, you know, 75 percent  
19 of the credit is due to the actinides.

20 CHAIR RYAN: The largest difference is in  
21 structural materials. Why?

22 DR. WAGNER: Pardon me?

23 CHAIR RYAN: A larger difference is in  
24 structural materials. Why?

25 DR. WAGNER: It's actually due, and then

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1 this was actually a good outcome of this work too, in  
2 terms of kind of shining the light on that a little  
3 bit, and so you picked up on that. But a lot of the  
4 structural materials, like the chromiums, the nickels,  
5 the irons, they actually have a lot of resonance  
6 behavior.

7 Now most of it's not in the thermal range,  
8 but because of that, there's actually a fair bit of  
9 nuclear data uncertainties in those cross-sections.

10

11 CHAIR RYAN: Okay, thank you.

12 DR. WAGNER: And that's what we're seeing.  
13 So that's another thing. While we focused a lot on  
14 validating the fission products, kind of it draws us  
15 back to going we've got to make sure we've got our  
16 structural materials well-represented in these  
17 critical experiments as well.

18 CHAIR RYAN: So that's really over a range  
19 of different kinds of structural materials in  
20 different settings. What's why the difference?

21 DR. WAGNER: Yes.

22 CHAIR RYAN: Thanks.

23 DR. WAGNER: So this talk is fairly high  
24 level, but the uncertainties due to the nuclear data  
25 uncertainties were investigated for special

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1 configurations as a function of burnup and a variety  
2 of other relevant parameters.

3 The point I'm trying to make here is that  
4 just like for the isotopic validation, for the  
5 criticality validation, we also looked at the  
6 sensitivity of our predictions to different ranges of  
7 relevant parameters. For like -- for example, the  
8 boron content in the cask and things like that.

9 In all cases, and there's a lot, there's  
10 several big tables in the NUREG. We found that the  
11 uncertainty due to nuclear data uncertainties was less  
12 than 1.5 percent of the reactivity worth of the  
13 actinides that we considered.

14 So this was important, because the question  
15 becomes how do we use this information? How does an  
16 applicant use this information? We say that the  
17 nuclear data uncertainty in our configuration is .1  
18 percent. But how does somebody else take that number  
19 and use that in a manner that's more general?

20 And so what we did is we characterized this  
21 in terms of the reactivity worth to the isotopes that  
22 they're trying to credit, and show that in all cases  
23 again, 1.5 percent of that worth was bounding what we  
24 saw.

25 So that enabled us to -- well, it will be in

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1 a minute, to have a general type of recommendation for  
2 others to use. So the recommendations that are in the  
3 ISG-8 are that you validate -- basically, you validate  
4 everything you can, to the extent you can, with the  
5 critical experiments that you have.

6 If we have perfect critical experiments, I  
7 would recommend that you use those, even for the  
8 fission products. But we don't. We do have them for  
9 the actinides. The actinides are the principle  
10 component that we need to be careful, that we need to  
11 be concerned about.

12 So we recommend that you validate the  
13 principle actinides with laboratory-critical  
14 experiment data, and we specifically focus on the HTC  
15 experiments. Our NUREGs have identified a number of  
16 MOX criticals in the international handbook that are  
17 applicable.

18 Then for the nuclides that you can't  
19 validate through laboratory-critical experiments, we  
20 suggest a conservative estimate of the combined bias  
21 and bias uncertainty associated with those nuclides to  
22 be 1.5 percent of their worth, of their work.

23 This estimate is appropriate provided the  
24 applicant, you know, just like the actinides, or just  
25 like the isotopic validation, provided they do similar

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1 things to make that number consistent with what  
2 they're doing.

3 We've since been looking at how can we  
4 expand that out to other codes, and particular other  
5 codes. So it's right in the version of the ISG-8.  
6 Drew will talk in a minute about some of the comments  
7 back on the ISG-8 and NRC's responses to those.

8 What's in the ISG-8 right now is that you  
9 have to use the SCALE code, with either five, six or  
10 seven cross-section libraries. If you use a different  
11 code, you have to use a higher bounding. Again, I'll  
12 let Drew talk about what the thinking is on maybe  
13 changing that.

14 Then similar initial assumptions, similar  
15 cask models. And we capped the ability to use this at  
16 ten percent k-effective, and for those of you who  
17 don't do this kind of stuff every day, the fission  
18 products and minor actinide credit increases as a  
19 function of burnup, and just kind of a realistic rule  
20 of thumb, be about three percent for low burnup, up to  
21 about ten percent for high burnups in the 50 to 60  
22 gigawatt-day kind of range.

23 So that's, you know, kind of where you would  
24 expect the fission products and actinide worth to be  
25 about, in maybe a 60 gigawatt-day kind of range. And

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1 that's my summary of those two NUREGs in a very quick  
2 period of time.

3 I'd like to acknowledge the NRC support for  
4 all this work. It's been quite rewarding, in the  
5 sense that this is the major technical issue I think  
6 we've been wrestling with for a long period of time,  
7 and I think we've got adequate resolution on this with  
8 these NUREGs.

9 CHAIR RYAN: Thank you, John. I appreciate  
10 that very much. Steve, where are we? Ah, let's see.  
11 Drew, we're back to you.

12 MR. BARTO: Yes. Unless there's any other  
13 questions or comments on John's presentations. Thank  
14 you. I wanted to talk at a reasonably high level  
15 about the public comments we received so far on the  
16 draft ISG.

17 We got three sets of comments, one from  
18 NEI, another from Stefan Anton out of Holtec  
19 International, and another from Dale Lancaster from  
20 Nuclear Consultants dot com.

21 I want to discuss the major comments in our  
22 proposed resolutions. I don't intend to go through  
23 every comment we got, but just sort of the --

24 CHAIR RYAN: That's good.

25 MR. BARTO: Just sort of what we perceive to

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1 be the major ones, and any of the commenters that are  
2 here, if you don't see it on this list, then that  
3 means we probably agreed with it and are going to  
4 incorporate it into the ISG.

5 The one major comment that we got from, I  
6 believe it was only from NEI, and it was a  
7 recommendation, probably a question more than anything  
8 about why isn't this material in a Reg Guide as  
9 opposed to an ISG, and our intention is really that we  
10 believe this guidance needs to be consolidated into  
11 one place for staff, as opposed to having some of it  
12 in an SRP and then referencing a Reg Guide, which  
13 would further reference these NUREGs.

14 So for the time being, we intend to have it  
15 as an ISG, and at the next revision of the SRP, to  
16 incorporate in the whole, into the SRP. The thinking  
17 is that this ISG format allows more flexibility to  
18 modify it in the future, and although this does  
19 represent a significant step in burnup credit, we do  
20 anticipate changes coming down the line.

21 I think EPRI is going to discuss how they  
22 have a different validation methodology that they're  
23 proposing and that we may, in some form, incorporate  
24 into our guidance in the future. The other big piece  
25 that's coming down the road is BWR burnup credit.

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1 We're eventually going to have recommendations for  
2 that that we'd like to incorporate into this.

3 So we leave open the option to consolidate  
4 this guidance into a Reg Guide at a later time. But  
5 for the time being, we're going to leave it as an ISG  
6 that will be incorporated into the SRPs.

7 I already mentioned the EPRI methodology  
8 that Albert is going to discuss. There was a  
9 recommendation in the comments that we explicitly  
10 point out in the ISG that there are alternative  
11 methodologies.

12 We will likely include text in the ISG that  
13 reinforces that, but the whole concept of the ISG is  
14 that this is one methodology that the staff has  
15 reviewed and found to be acceptable, and it's one path  
16 that we're identifying as sort of the path of least  
17 resistance to get an approval.

18 It by no means excludes all other  
19 methodologies, and any other methodology that would  
20 come in would be reviewed on a case by case basis. So  
21 we will reinforce that in the ISG.

22 We talked already at some length about  
23 misloads, and as I stated, we previously only had a  
24 recommendation to do a confirmatory burnup measurement  
25 to prevent misload, and we've since revised the ISG to

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1 include an alternative to that, which is performing a  
2 misload analysis, accompanied with additional  
3 administrative loading procedures.

4 We've got -- we received one comment that  
5 suggested that we simply remove the burnup measurement  
6 option. We are going to leave that in the ISG as an  
7 option, you know. We believe most applicants will  
8 probably choose the path of doing the misload analysis  
9 and incorporating these additional procedures.

10 But there is always the potential that even  
11 for some systems with the misload analysis, you may  
12 not be able to demonstrate adequate subcriticality, in  
13 which case measurement might be a better option.

14 And also, thinking into the future, you know  
15 right now, I believe most applicants and utilities  
16 would find the measurement techniques that are  
17 available to be burdensome, out of core, in the pool  
18 with additional equipment.

19 But there's always the possibility in the  
20 future that there's an easier measurement technique  
21 that may make that option more appealing than doing  
22 the misload analysis. So the bottom line is we're  
23 going to leave it in there as an option.

24 We got a good deal of comments on our  
25 recommended loading procedures, that are intended to

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1 accompany a misload analysis, and there was -- at  
2 least in one set of comments, there was a -- they  
3 proposed taking out the ones that we had recommended  
4 and putting in a completely different set.

5 We looked at those that had been proposed,  
6 and our view of what had been proposed is that those  
7 procedures were things that should already be done for  
8 cask loading procedures, even if you're not  
9 considering a burnup credit. There's a couple of  
10 examples listed on this slide, you know, verify the  
11 identity of the fuel assembly prior to loading, you  
12 know, reverify them prior to closing the cask, and you  
13 know, all of the lists.

14 I've got a backup slide that has the  
15 complete list on it, but it's all sort of things like  
16 this that you would expect to be done already, and  
17 that we routinely see incorporated into cask operating  
18 procedures for casks that don't include burnup credit.

19 So our view of the administrative loading  
20 procedures is that they should be additional  
21 procedures for a burnup credit cask, targeted at  
22 reducing the likelihood or consequences of high  
23 reactivity misload.

24 Again, these are just a couple of examples  
25 of things that we've recommended, such as assuring

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1 that you have no fresh fuel in the pool during system  
2 loading, since we've not considered fresh fuel as a  
3 misload possibility.

4 Verification of the location of high  
5 reactivity fuel, both prior to and after loading, and  
6 then independent third party verification of the  
7 loading process, as we've already discussed a little  
8 bit. And again, this is just a sampling of I believe  
9 six or seven recommended procedures that are in the  
10 direct ISG --

11 CHAIR RYAN: Drew, just to kind of ask a  
12 question about that.

13 MR. BARTO: Sure.

14 CHAIR RYAN: Severely underburned fuel, what  
15 handbook do I look up what that is? I'm trying to  
16 think. Are you looking at a burnup number or is there  
17 a better way to express that, or does everybody  
18 understand severely underburned fuel?

19 MR. BARTO: I don't think there's any  
20 official definition of it anywhere, but you know, as  
21 we've -- if you go back to what I was discussing  
22 earlier about the misload analysis criteria that we've  
23 recommended, we came up with somewhat of an ad hoc  
24 definition of a severely underburned assembly, and  
25 it's an assembly that would bound 95 percent of the

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1 underburned fuel population, with 95 percent  
2 confidence in terms of reactivity.

3 CHAIR RYAN: Ahh. So in terms of reactivity  
4 is the metric?

5 MR. BARTO: Right. So there's no burnup  
6 value, but it would be -- you know, for a specific  
7 cask system, it would be a burnup value that would  
8 vary with initial enrichment.

9 CHAIR RYAN: I think maybe it's just me, but  
10 I mean telling a little bit more about what it is you  
11 mean by that when you define this, or you should  
12 define it, would be helpful. Because you know,  
13 whenever there's a qualitative statement like that,  
14 you're going to get a lot of opinions about what it  
15 means sooner or later.

16 Even if you trained everybody on the first  
17 day, they'll go no, no, let's do it this way, because  
18 it is severely underburned, and I think this is a  
19 better way to express it. So I just caution that, you  
20 know, a little bit more analytical view of it might be  
21 helpful. Those are just my thoughts.

22 MR. RAHIMI: Yeah, yeah. Well, we'll do it.  
23 Actually, maybe in the parenthetical statement, we  
24 should have said "i.e., 95 percent of the  
25 underburned."

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1 CHAIR RYAN: Or see this report, which tells  
2 you more about it, or however you want to do it.

3 MR. RAHIMI: That's right.

4 CHAIR RYAN: But just to say "severely  
5 underburned fuel" and not point me to the right  
6 understanding of that would be a missed opportunity.

7 MR. RAHIMI: Yeah.

8 CHAIR RYAN: Okay.

9 MEMBER SKILLMAN: It seems back on Slide 53,  
10 the several bullets that you've identified are the  
11 ones that are the classical way people think about  
12 loading casks. But the events that you pointed to are  
13 not those types of events.

14 MR. BARTO: Right.

15 MEMBER SKILLMAN: The events that you  
16 pointed to are failures to understand either load or  
17 some other parameter. So as I look at your Slide 54,  
18 it doesn't appear as though you've pinpointed that  
19 systematic error or that process error as part of your  
20 recommendation.

21 Is it your intention to make sure that the  
22 recommendation that points to either the process or  
23 systemic error, or the events from Palisades and  
24 McGuire and Grand Gulf?

25 MR. BARTO: I think the third sub-bullet

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1 there under the first bullet is intended to get at  
2 that, you know, independent verification of the  
3 loading process to include selection of fuels at  
4 least.

5 MR. RAHIMI: Yeah, and I think that is a  
6 point well-taken, that it goes back to earlier  
7 discussion, that we've got to define that verification  
8 going all the way back to the beginning of the  
9 process.

10 (Simultaneous speaking.)

11 CHAIR RYAN: --stuff on the diagram, that's  
12 where it all -- that's where the action is.

13 MR. RAHIMI: Yes.

14 CHAIR RYAN: But nothing -- I mean I'm not  
15 sure it does, but that's where maybe the root problem  
16 is. So that to me is kind of the takeaway message.

17 MR. BARTO: And again, I think, you know, we  
18 want to include these procedures, because we believe  
19 that, you know, particularly this one that I'm talking  
20 about, will reduce the probability. However, there's  
21 a lot of room to make them not credible. We're down  
22 in the 10 to the minus 2 range.

23 So I think regardless of what you do, you're  
24 looking at a situation where there are going to be  
25 misloads. So our view has been analyze for them or

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1 measure each fuel assembly to show it's the one that  
2 you think it is and demonstrate that you're not going  
3 to have a criticality issue, even if you have one.

4 CHAIR RYAN: Even if you have a misload.

5 MR. BARTO: Right.

6 CHAIR RYAN: Yeah.

7 MR. BARTO: So we can certainly, you know,  
8 as you say, pull the string on it a little further and  
9 see what we can do to further reduce that --

10 CHAIR RYAN: Yeah. Maybe I'm thinking ahead  
11 and shouldn't be speculating at all, but it seems to  
12 me that this kind of a topic is ripe for an appendix,  
13 to walk people through it, as we can go wrong at this  
14 step and all the way through and kind of road map a  
15 little bit, so you give people the insights as to what  
16 they have to be looking for. It was just a thought.

17 MR. BARTO: Okay, that's good. A little  
18 takeaway. So I guess the bottom line with the  
19 administrative loading procedures is we're going to  
20 not adopt the list that we got as a comment.  
21 However, there were significant comments on each of  
22 the individual, recommended individual procedures, and  
23 we will end up revising that, and I'll talk about that  
24 right now.

25 We, in our list of recommended procedures,

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1 we had two that got at fresh fuel. So we had one that  
2 said ensure that there's no fresh fuel in the pool at  
3 time of loading, and then an additional one that  
4 required qualitative verification of burnup, this --

5 It's not stated explicitly in the ISG, but  
6 this basically means look at them, you know, because  
7 they are so visually different.

8 A point was made in the comments that these  
9 are essentially redundant, and although fresh fuel is  
10 not routinely in the pool during loading, we have had  
11 some discussions with licensees and vendors that have  
12 stated that there are situations where fresh fuel  
13 could be in the pool.

14 So we intend to revise that to be a single  
15 recommended administrative procedure that would give  
16 a cask user the option, you know, either of  
17 demonstrating you don't have it or incorporate a step  
18 in your loading procedure, where you verify that  
19 you're not putting fresh fuel in the cask.

20 And you know, this has to somewhat recognize  
21 that there's a tremendous financial incentive to not  
22 putting fresh fuel in a -- sealing it inside a storage  
23 casket. So it's, I think the staff does not think  
24 that this is going to come up basically.

25 And then that's what steered us towards our,

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1 you know, rather than looking at fresh fuel, looking  
2 at severely underburned fuel in the misload analysis.

3 There was another recommendation for a full  
4 pool audit within one year of loading, as an  
5 administrative procedure. One of the commenters  
6 pointed out that this is -- this overlaps in a 10  
7 C.F.R. 74 MC&A requirements, and we might be sort of  
8 adding additional requirements on top of that.

9 And it was somewhat duplicative of another  
10 administrative procedure that we recommended, where  
11 you verify the location of high reactivity assemblies,  
12 both prior to and after loading. So I think --

13 CHAIR RYAN: Well how would you verify the  
14 already-loaded canisters --

15 MR. BARTO: This is for -- I mean you put a  
16 cask -- before you put the cask in the pool, you make  
17 sure you know where your high reactivity fuel is.

18 CHAIR RYAN: Yeah. Oh, okay, all right.  
19 Sorry.

20 MR. BARTO: And then, you know, you go  
21 through the whole loading procedure. Before you seal  
22 it up and take it out of the pool, you make sure  
23 they're still there.

24 CHAIR RYAN: Got it.

25 MR. BARTO: And the idea is that it should

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1 be a small number of assemblies.

2 CHAIR RYAN: Got you.

3 MR. BARTO: So how we intend to revise this  
4 particular recommendation is to turn it into a QA  
5 audit of already-loaded canisters. As we've stated  
6 before, there's upwards of 1,500 systems already  
7 sealed and loaded, sitting on pads that most of which  
8 are going to require burnup credit.

9 So the question becomes how do you verify  
10 that you don't have misloads in those? So prior to  
11 transport, there would have to a rule recommending  
12 that there was a QA audit to determine that those have  
13 been properly loaded.

14 And there were a number of other minor  
15 comments on, or what we consider to be minor comments  
16 on the administrative procedures that we recommended.  
17 So we're going to do our best to clarify the intent of  
18 those. I'm not going to discuss them specifically  
19 now.

20 CHAIR RYAN: Okay.

21 MR. BARTO: We got a number of comments on  
22 our misload analysis recommendations. We had some  
23 language about the administrative margin for the  
24 misload analysis. It was similar to language that we  
25 found in other regulated areas for criticality safety,

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1 where you use a reduced administrative margin, where  
2 the .02 is basically the minimum administrative  
3 margin.

4 But any margin less than .05 would have to  
5 be justified. So the question is was -- what do we  
6 consider to be properly justified, and we are still  
7 sort of internally iterating on that.

8 We want to go back and look at the other  
9 areas where we found this language, and discuss what  
10 it is that's being sought for justification for  
11 administrative margin. So we still have some work to  
12 do on that.

13 There was a couple of recommendations that  
14 we got in the comments for different misload analysis  
15 criteria, and the theme of these comments is that  
16 this, what's being proposed would be simpler, and we  
17 agree. It would be simpler, but it might be overly-  
18 restrictive.

19 For instance, for the single high reactivity  
20 misload, the recommendation was make it a single fresh  
21 fuel assembly. If a vendor were to come in and with  
22 that sort of criticality analysis for the misload,  
23 that would obviously be acceptable.

24 But we know from our previous misload  
25 consequence work that a single five weight fresh fuel

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1 assembly can easily overwhelm your administrative  
2 margin. You can get as much as a five and a half  
3 percent in k-effective increase from a single fresh  
4 fuel assembly in a burnup cask.

5 So it's probably not going to be doable for  
6 most vendors, and you know, we've already discussed  
7 that we've got procedures that would, that we believe  
8 would mostly eliminate any possibility of loading a  
9 fresh fuel assembly, and that's why we concentrated on  
10 the burned, yet still relatively reactive assemblies  
11 that we know exist in some spent fuel pools.

12 MR. RAHIMI: But however, you know, if the  
13 vendor wants to do a fresh fuel misload analysis,  
14 they're more than welcome, you know. That's the  
15 comment, you know, why not do a fresh fuel misload?  
16 By all means. Yeah, that is acceptable. That's a lot  
17 more conservative.

18 CHAIR RYAN: Okay.

19 MR. BARTO: And then for the multiple  
20 assembly misload, the recommendation that we received  
21 is that, you know, rather than determining this 90  
22 percent threshold for the total discharged fuel  
23 population, why don't we do something that's simpler,  
24 which is 25 percent, assume the burnup is 25 percent  
25 below what is required for half, half the assemblies

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1 in the cask.

2 And again, we agree that this is simpler and  
3 in some cases is more restrictive. However, it really  
4 depends on loading curve. If you've got a loading  
5 curve that only permits say 20 or 25 percent of the  
6 fuel population to be loaded, going to a 25 percent  
7 underburn criteria is not as restrictive as the 90  
8 percent criteria that is in the draft ISG.

9 So I think, you know, we're intending on  
10 leaving this recommendation for multiple assemblies,  
11 burned to a level that bounds 90 percent of the total  
12 inventory in place, although we will, you know, we  
13 will obviously consider other, you know, alternative  
14 criteria as they're submitted to us.

15 And then one thing that the 90 percent  
16 criteria allows for is that it doesn't -- that 90  
17 percent, the line doesn't move depending on the cask  
18 design. It's dependent entirely on the discharged  
19 fuel population.

20 So it's conceivable that you could design a  
21 cask where the loading curve already encompasses 90  
22 percent of the fuel, in which case you might not have  
23 to perform that analysis.

24 CHAIR RYAN: Right.

25 MR. BARTO: There were a number of other

1 comments that I'll try to run through reasonably  
2 quickly. There was a request for some language about  
3 how to credit additional isotopes beyond the 28 that  
4 we recommend. So we're intending on modifying the ISG  
5 to state that you may credit those, provided that  
6 there's quantification of the bias and bias  
7 uncertainty associated with those nuclides.

8 There was a recommendation that we, or  
9 comment that we should somehow address BWR burnup  
10 credit in the ISG. Again, as we've already discussed,  
11 we've got a research project upcoming on BWR burnup  
12 credit, and we'll have, likely have recommendations on  
13 that in the future.

14 Right now, though, we don't have -- we  
15 haven't settled on explicit recommendations for BWR  
16 burnup credit. But we will revise the ISG to state  
17 that we'll look at those on a case-by-case basis.

18 We did not, ISG Rev 2 has an applicability  
19 section that states that it's only applicable intact  
20 fuel, which was our recommendation at the time. We  
21 didn't change that applicability section moving  
22 forward with this draft, but we have already looked at  
23 burnup credit analyses that consider damaged fuel and  
24 other variations that are less than damaged.

25 So we're going to revise this section to

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1 basically incorporate what we've done so far, which is  
2 basically -- I mean basically that you may do it, but  
3 you need to consider fuel reconfiguration and any  
4 other uncertainties associated with it.

5 MEMBER ARMIJO: As long as you have  
6 maintained the geometry of the assembly. For example,  
7 a pinhole failure in the cladding would be, is that  
8 considered damage?

9 MR. BARTO: Pinhole leaks and hairline  
10 cracks are not considered damaged. We have another --

11 MEMBER ARMIJO: Fractures of the fuel rod or  
12 missing sections of the fuel or something like that.  
13 It has to be pretty gross then.

14 MR. BARTO: Well, I think the way we're  
15 going to revise the ISG is that as long as you  
16 consider fuel reconfiguration in a bounding fashion,  
17 then you can use burnup credit even for damaged fuel,  
18 or severely damaged fuel.

19 MR. RAHIMI: Because the basis of all these  
20 isotopes that we are recommending, they had to pass  
21 three criterias. They have to be non-gaseous, non-  
22 volatile, stable. So at this point, we don't see  
23 anything that make applying burnup credit to  
24 reconfigured fuel or damaged fuel invalid.

25 So unless, you know, we can think of

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1 something. But at this point, we can't think of  
2 anything that would make it invalid for damaged fuel.

3 CHAIR RYAN: Okay.

4 MR. BARTO: We got a comment about how we  
5 apply bias and bias uncertainty terms, both for the  
6 depletion code and the criticality code. The way  
7 we've reported bias and bias uncertainty in the ISG  
8 currently is to combine them, and as John stated, for  
9 the ENDF/B-VII data, it's not so much of an issue,  
10 since the bias term is zero.

11 But we've sort of reported it as a combined  
12 bias and bias uncertainty that you would add directly  
13 to your calculating k-effective, and our commenters  
14 have, we believe, correctly pointed out that that's  
15 not entirely, an entirely accurate way to do, and that  
16 your uncertainty terms are typically statistically  
17 combined with each other.

18 So we're going to revise the ISG to state  
19 that this, at least for the depletion code, the  
20 uncertainty that's -- the bias uncertainty that's the  
21 reference value that's reported there may be  
22 statistically combined with the other calculation  
23 uncertainties.

24 However, the criticality code uncertainty,  
25 this delta k sub-x term, is -- we're going to treat

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1 slightly different. It is an uncertainty in k-  
2 effective due to uncertainty in the minor actinide and  
3 the fission product cross-section data.

4           However, we have no information on for minor  
5 actinides and fission products to determine a bias,  
6 how you would routinely do that in criticality safety  
7 space. So what we're saying is that this uncertainty  
8 that's calculated is basically bounds the bias.

9           So we don't know what the bias is, but it  
10 may be as big as this term. So we are conservatively  
11 treating it as a bias that will be added directly to  
12 the calculated k-effective, and we will clarify that  
13 in the ISG.

14           CHAIR RYAN: Good.

15           MR. BARTO: The last comment that I'm going  
16 to discuss is the reference values in the NUREGs are  
17 reported for the SCALE code system with ENDF/B-V, -VI  
18 or -VII data for criticality, and the recommendation  
19 is that that delta k sub-x term should be one and a  
20 half percent of the minor actinide and fission product  
21 worth for the SCALE code system.

22           Currently, the recommendation is that you  
23 would double that number for other code systems. We  
24 had a lot of discussion with our colleagues at Oak  
25 Ridge about what's appropriate to do for other codes,

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1 keeping in mind that when we say "other codes" that  
2 use ENDF/B-V, -VI or -VII data, we're talking almost  
3 exclusively about MCNP.

4 So the thought was that with a code that's  
5 as well-qualified as MCNP, there shouldn't really be  
6 a significant difference in the bias, as long as it's  
7 using that same data set. However, we had some  
8 questions about how each code handles the cross-  
9 section data, and the thought was there might be --

10 CHAIR RYAN: Wasn't there some calculational  
11 assessment of that, whether they should be the same or  
12 not?

13 MR. BARTO: That's what we're going to  
14 recommend. Currently, we just say double it and don't  
15 do anything. I think it's been suggested in a couple  
16 of the comment sets, that we provide an option to do  
17 a worse comparison.

18 So you calculate the minor actinide and  
19 fission product worth with the SCALE code system,  
20 calculate it again with the MCNP system and compare  
21 the results.

22 If they're using data in the same way, you  
23 should get very similar answers. So as long as the  
24 worths are comparable, then you may use the same one  
25 and a half percent number for delta k sub-x.

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1 CHAIR RYAN: That's right. Okay.

2 MR. BARTO: I guess in conclusion, we're  
3 extending the ethical basis for burnup credit for  
4 fission products and minor actinides, providing an  
5 alternative to the confirmatory burnup measurement  
6 that was in ISG Rev 2.

7 The ISG has been generally well-received by  
8 industry, with some comments as I've just discussed.  
9 So we will, our next step is to resolve the comments  
10 into a final ISG, and present this to the full ACRS in  
11 September.

12 CHAIR RYAN: That's great.

13 MR. BARTO: This is just a backup slide.

14 CHAIR RYAN: Well, I thank you for being so  
15 thorough in such a relatively short period of time.  
16 We're really getting a lot of information this  
17 morning. We appreciate it. I guess we're scheduled  
18 now for two briefings, one from EPRI and another one  
19 from NEI.

20 So if we can do a quick change around the  
21 table and gather up the speakers, and again, thank you  
22 all very much for a very informative presentation.

23 MR. BARTO: Thank you.

24 (Off record comments.)

25 MR. MACHIELS: Good morning.

1 CHAIR RYAN: Your name, sir.

2 MR. MACHIELS: My name is Albert Machiels  
3 and I'm with EPRI, and thank you for the opportunity  
4 to present some material which I hope you will find  
5 relevant to the discussion that you've had today. My  
6 intent is to come back to discuss or to present  
7 information on a couple of items.

8 The first one is the probability of  
9 criticality run during transportations, which build up  
10 on the misload analysis that has been already  
11 discussed to some extent. This is work that we did a  
12 number of years ago, four, five, six years ago, and it  
13 had to do within the context of transporting high  
14 burnup fuels. So the high burnup picture will also be  
15 mentioned a number of times.

16 The second topic is I'm going to talk about  
17 burnup credit validation. This is recently completed  
18 work, and it has been motivated really by a different  
19 application, criticality analysis in spent fuel pool.  
20 But the work that we did under that context, I believe  
21 fits very well also in the context of transportation.

22 Now what I'm going to talk about is not to  
23 detract of the information that we have received  
24 today. I think it was properly characterized of the  
25 ISG having been very well-received and being a

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1 significant progress over Rev 2.

2 But what I want to do is at least provide  
3 some additional information that might be of interest  
4 to the topic that we're talking about. So with regard  
5 to brief introducing criticality safety and burnup,  
6 which we got to brief the criticality safety, we'll  
7 just mention that the standards and the methodologies  
8 were originally developed for the front end of the  
9 fuel cycles, with fairly pure materials.

10 So at that time, we were talking about  
11 critical analyses of simple mixture like enriched  
12 uranium or plutonium. Those involved particular  
13 species like enriched uranium with some relative  
14 isotopic content, or plutonium maybe, which is a  
15 handful of species.

16 Now spent fuel is a challenge, because what  
17 makes a lot of sense for a simple situation is very  
18 complicated, that in spent fuel obviously you have a  
19 large number of nuclides involved. Clearly, a lot of  
20 those will disappear very quickly because of their  
21 half life.

22 But still when we talk about composition of  
23 spent fuel after some time, we still have to deal with  
24 about 400 nuclides of interest. Clearly, a  
25 methodology which is allowed to look at nuclide per

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1 nuclide become less practical when you have to talk  
2 about a very large number of nuclides.

3 So spent fuel is an issue when we talk about  
4 criticality analysis, in terms of relating how these  
5 safety methods have evolved over time. So one way to  
6 alleviate this complication about the fresh fuel  
7 assumption; as you know, that introduces a significant  
8 amount of conservatism, especially as the fuel designs  
9 have evolved to higher enrichment.

10 If you follow that, you end up with a low  
11 capacity system for storage and transportations, which  
12 means more systems, more operation, increased cost and  
13 overall, this approach typically, especially in  
14 transportation, would not result in the optimal  
15 safety.

16 The reason being is that the non-  
17 radiological risks dominate the radiological risks.  
18 If you take transportation, for example, by truck, the  
19 classic accident rate just of normal transportation  
20 overwhelms the risk coming from the radiological side.

21 So from that point of view, from a point of  
22 view of minimizing risk, the idea is to minimize the  
23 number of shipments. That means to maximize the  
24 loading for a given -- a capacity for a given volume.

25 And so burnup credit has already been

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1 mentioned. It's simply giving credit for the reduced  
2 reactivity of spent fuel compared to fresh fuel, and  
3 that has been the evolution that the NRC has below for  
4 transportation for the first version of the ISG back  
5 in '99.

6 As already discussed, the burnup credit  
7 comes in different flavors. You have actinide only,  
8 then you have actinide-only plus a subset of a fission  
9 products, which have been extensively discussed, with  
10 including some minor actinides.

11 Then there's the full burnup credit, which  
12 basically you don't leave anything on the table, but  
13 you're going to try to take advantage of everything  
14 which is in the spent fuel.

15 The technical challenge with those as has  
16 been indicated is to be able to calculate the  
17 uncertainty of the biases that may come with some of  
18 those different subsets. From that point of view, in  
19 my case, what I'm going to talk is about the full  
20 burnup credit, the last one.

21 That means that we are looking at spent fuel  
22 as an entity, without neglecting any part of it. We  
23 could arrive to the same system by basically looking  
24 at all the nuclides in the spent fuel. But it would  
25 entail basically a large amount of work, and also are

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1 collectively then a lot of fission products which have  
2 very little impact on the criticality analysis.

3 Together, a large number of them may have an  
4 impact. But if you look at them individually,  
5 individually they have little impact and it would come  
6 with fairly large uncertainties, that you basically  
7 would get to negative feedback if you want to include  
8 more things with larger uncertainties.

9 So basically what we're going to look at  
10 eventually is the full burnup credit approach. But  
11 before I get into that full burnup credit approach,  
12 I'm going to the dark side for a moment, and say that  
13 with regard to regulations, we have a fairly simple  
14 requirement with regard to subcriticality. It has to  
15 remain basically subcriticality, subcritical and in  
16 all conditions, normal and accident.

17 Normal means that you have control of  
18 things. That means you're doing things the way you  
19 expect to do them. So your cask is designed for that  
20 and this is an issue. For accidents, it's a  
21 difference. It's a loss -- accident is a loss of  
22 control. There are things that are happening  
23 obviously, that you don't have to happen typically.

24 And with regard to the NRC positions, this  
25 is where the high burnup picture gets into the

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1 picture, is that when the burnup of the fuel is less  
2 than 45 gigawatt-days per metric ton, the NRC assumed  
3 that in that case, the impact loadings resulting from  
4 accidents results in the fact that there's not much  
5 change in the geometry of the assembly within its  
6 normal configuration.

7 That means that all the analyses that you  
8 made for normal configurations will hold for accident  
9 conditions as well. However, when we talk about high  
10 burnup, there are definitely some questions about how  
11 the cladding would behave, and in that case, it's not  
12 straightforward to assume that it would be the case.

13 That means now you basically have options  
14 right now to say well, even if there's damage, there  
15 won't be any water because of there's all these  
16 reasons, or you can make an analytical simulation  
17 which says those are the worst conditions for  
18 reconfigurations, and calculate the impact on  
19 criticality.

20 The observation is that there are sort of  
21 contradictions in this to the extent that clearly,  
22 high burnup means that you have achieved somewhat  
23 something equal or larger than your designed burnup,  
24 and that means that the reactivity, the leftover  
25 reactivity is very low, okay.

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1           If for reason that you suspect that now  
2           you're dealing with something which has a very low  
3           reactivity compared to what it means, that means also  
4           that the cladding has a half life basically that led  
5           to a low burnup. So you could assume really that if  
6           you have significant underburning, whatever it means,  
7           is that the normal configuration would be assumed.

8           Which means that with burnup, if you assume  
9           that the life of the reactor will lead to  
10          deterioration of the cladding, such that it will  
11          eventually this property will degrade over time, as  
12          the cladding properties degrade, that means that the  
13          burnup has been fairly high.

14          From a criticality point of view, the more  
15          burnup you have, the better it is obviously, because  
16          you have the reactivity very low.

17          Now there has been some scenario which have  
18          been considered, and published in an Oak Ridge report,  
19          and some scenario though really beyond critical  
20          conditions, as I will mention, and according to the  
21          report, they represent the theoretical limits of the  
22          effect of severe accident conditions.

23          Certainly, we agree that they go beyond  
24          critical conditions, but I think have some question  
25          about their represented theoretical limits.

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1           An example which is easy to visualize is  
2           that you would have an assembly, and as a result of an  
3           impact, basically all the cladding would basically be  
4           removed, and what you would have basically is a column  
5           of fuel, which would maintain the identical geometry  
6           as in the assembly, but without any cladding  
7           supporting them. This is obviously beyond critical  
8           conditions.

9           Now even in those type of scenario, the  
10          calculations in terms of increasing k-effective, which  
11          basically is fairly small, to the extent that they are  
12          less than five percent, .05 compared to 1 for a case  
13          like this, which means that even if you would assume  
14          that Mother Nature would not behave the way it's  
15          supposed to, is that you would go from a normally  
16          designed cask, which has a k-effective of equal or  
17          less than .95, to something which is less than 1, even  
18          assuming those more drastic scenarios.

19          And this obviously is something which  
20          indicates that it's not possible to get the  
21          reconfiguration in such a way that you would get  
22          criticality. We did some similar work, and we came to  
23          the conclusion that actually k-effective is much more  
24          likely to decrease rather than increase as a result of  
25          reconfiguration, and the very simply reasons for that

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1 is that PWR assemblies tend to be fairly optimized to  
2 start with.

3 That's the way they are designed. The  
4 environment in a PWR is fairly uniform, and deviations  
5 from the normal conditions tend to over-moderate or  
6 under-moderate, while the ideal is actually the normal  
7 conditions. From a reactivity point of view, the most  
8 reactive configuration is actually the actual geometry  
9 of the assemblies, at least for PWR.

10 Now shifting a little bit still in the  
11 accident, in the risk domain, let's look at misload.  
12 We looked at that some close to ten years ago, and you  
13 see a curve here where we assume that we have a cask  
14 which is loaded with a fuel burned to 45 gigawatt-days  
15 per metric ton with the initial enrichment of being  
16 five percent.

17 And you can see on the X axis that the k-  
18 effective calculated is somewhere around between .85  
19 and .9. Now each point now indicates on -- going  
20 along the curve indicates a misload, which means that  
21 here, this is no misload and here, I have a misload  
22 where I put something instead of being 45, I put a 25,  
23 and I put in the center of a cask, which is the more  
24 favorable position from a criticality point of view.

25 They introduced a second one, a second

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1 misload next to it, in order to maximize the effect,  
2 a third one, a fourth one and so on. So basically  
3 increase the misloading, replacing each time a 45 by  
4 a 25. You can see basically how the k-effective  
5 increased.

6 Now the red curve is basically when you load  
7 a fresh fuel assembly, a five percent fresh fuel  
8 assembly. It will jump by about six percent by one  
9 misload, by another six to five percent or roughly by  
10 a second misload, if you put it again at the center  
11 and next to it.

12 So what it shows is that in this case, it  
13 would take about two to three misloads of a five  
14 percent to go beyond criticality conditions, and with  
15 regard to misloading with 25, it basically takes,  
16 doesn't get there.

17 Now this is basically a calculation starting  
18 from this point. The NRC will license and assume that  
19 the licensing conditions start at .95 now. Basically  
20 you have the limiting conditions, which are .95 and  
21 assuming this is true physical value, not including  
22 all the conservatism which are built in to make it  
23 .95.

24 Then you would start basically those curve,  
25 starting roughly at .95. You will see that to get at

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1 1, it would require several misloads, three to five  
2 misloads of underburned assembly to get the critical  
3 conditions, but it would take a single fresh five  
4 percent assembly to go from .95 to over 1. So you can  
5 see the impact of misloading in a situation like this  
6 one.

7 Now we typically have disregard loading  
8 fresh fuel assemblies as being a potential for the  
9 following reasons. Some have been mentioned already,  
10 is that typically, the loading cask and refueling a  
11 reactor are done at different times of the year, and  
12 an example is TVA. Of 33 cask loadings, 33 cask  
13 loadings, two of them have fresh fuel and 31 of them  
14 didn't have fresh fuel in the pool.

15 Second thing is that the physical appearance  
16 of a fresh assembly compared to a once-burned assembly  
17 is different, as you can see on the picture.

18 So at least this is a visual check, and the  
19 last one is that the economic value of a fuel  
20 assembly, a fresh fuel assembly is over \$1 million,  
21 and clearly, you don't lose track easy of something  
22 which costs \$1 million, is that there will be  
23 obviously something that will prevent that misload of  
24 cask to be sent on the road with a fresh fuel in it.

25 So from that point of view, misloading of

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1 fresh fuel, from our point of view at least, is not  
2 really a credible event for the number I mentioned,  
3 and with regard to multiple misloading, it requires  
4 significant underburnup. It would take typically  
5 several assemblies to be misloaded.

6 But as we have seen, it's not an  
7 unreasonable assumption, given as we can see, how the  
8 errors can introduce themselves.

9 So what we did is that we did basically this  
10 type of work about five years ago, and what we did is  
11 that we started from the very beginning, excuse me,  
12 where we actually, the utility received fresh fuel to  
13 be loaded in the reactor.

14 Then we follow the fresh fuel upon reloads  
15 until it's discharged, and then the preparation of the  
16 sheets for loading, unloading and so on, and that we  
17 used as reference the plant procedure of a plant and  
18 our contractor was located in southern California, in  
19 Irvine. There is a plant which is located nearby  
20 basically.

21 We basically interviewed the plant and  
22 applied the procedures, and we also introduced some  
23 recommendations, in terms of how to manage the  
24 database, which is very foreign, and also we made an  
25 additional recommendation that when you get at the end

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1 of life here, and you have your cask sitting, is to go  
2 back and look at the records, and go back to the  
3 original reactor records.

4 That means you make the relationship again  
5 between the assembly and the records from the  
6 reactors, such that some of the discussion that we had  
7 that if an error happens, basically that you don't,  
8 you are unable to correct it, is that actually you're  
9 able to do that.

10 The reason is basically based on the  
11 discussion that we had earlier, is that the key issue  
12 is basically introduction here in the database here as  
13 you go along, and there will be plenty of opportunity  
14 to basically correct picking the wrong assembly.

15 To our knowledge, that has not ever happened  
16 that somebody picked the wrong assembly, at least  
17 having been documented and put it into a cask. But at  
18 least there are records of paper issues and  
19 configuration management.

20 So that's what we did, and then we looked,  
21 since this is a 32 PWR assembly, this is railroad  
22 transportation, the Federal Railroad Administration  
23 database. Plenty of data will give you plenty of  
24 information about statistic about accidents, hazmat  
25 transportations, the velocity of the train, what did

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1 happen and so on.

2 Then finally we got what is the probability  
3 of if you have an accident. An accident is large  
4 enough, is severe enough that there is a defect in the  
5 cask. Water is present, and basically, you know that  
6 you have motivation for criticality.

7 When you put those together, you can see  
8 that -- you can see this is a very small number to  
9 start with, okay, and although it's a small number,  
10 it's likely to be even smaller now because this work  
11 was done many years ago, and the updates, which have  
12 been done in that, indicate what the methods  
13 available, that the frequency or probability of this  
14 is probably several orders of magnitude compared to  
15 what we used.

16 The next one is this one here, and that's  
17 assuming that all the recommendations that we made  
18 were implemented, because we get credit obviously for  
19 recovery, and then finally the last one that  
20 contributes to the risk is this one.

21 The bottom line is that when you look at all  
22 those factors, the likelihood of a potential  
23 criticality event during a 2,000 mile railroad  
24 shipment of casks designed for 32 PWR assemblies is  
25 basically extremely low, or about 10 to the minus 16.

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1           Now you can see, this is a point estimate,  
2           and you can change those numbers. For example, if you  
3           don't implement the recommendation that we made in  
4           these studies, this can increase by a factor of three,  
5           10 to the minus 13. On the other hand, if you put  
6           some restriction on velocity of the train, for  
7           example, not going over a certain velocity, then you  
8           reduce the probability of a severe accident, and you  
9           can lower this number by another couple of orders of  
10          magnitude.

11           So there is obviously this is not an  
12          accurate number, but depending basically how you  
13          handle the numbers here, you get something which is in  
14          our case extremely small, but with a pretty broad  
15          range of values, depending on what you do or what you  
16          don't do.

17           Okay. So away from accident conditions now,  
18          and going back to the main thrust, which is a  
19          conservative estimate of the loss of significant  
20          reactivity as a function of burnup, range up to 60,  
21          and with obviously a requirement of coming within an  
22          uncertainty of an estimate.

23           We basically adopted a different approach,  
24          which came from the spent fuel pool environment,  
25          because in that case, they always have so far used a

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1 full burnup critical approach, and the estimate was  
2 based on a genuine judgment, which was based on some  
3 understanding and the accuracy of the code to predict  
4 a number of things.

5           And so what we did is we went back, because  
6 you have -- basically in a reactor environment, you  
7 have fuel at the beginning of cycle, from fresh fuel  
8 to something which has been burned through roughly one  
9 cycle. Then at the end of the cycle, you have  
10 something, a range of burnup from something which has  
11 been burned through one cycle, to something which is  
12 ready to discharge.

13           So you have a true representation and  
14 sampling of burnup from zero to basically the point of  
15 discharge here. We do that by doing, not taking  
16 advantage of the measurements which have been done in  
17 the reactor, flux map essentially, which are required,  
18 are part of operating the reactor.

19           And so we entered into a cooperative effort  
20 involving Duke Energy, Studsvik Scandpower, and a lot  
21 of that was inspired by Dale Lancaster, Dr. Dale  
22 Lancaster. The principal investigator was Professor  
23 Kord Smith, who's now an endowed professor at MIT.

24           And what we did is basically collected data  
25 from four PWR loop reactors, over 600 flux maps, and

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1 over a million data points basically. And this  
2 represents basically the core here, it's maybe hard to  
3 see. But without looking at any number in particular,  
4 where you see a square where there are numbers, those  
5 obviously are the instruments, the location of  
6 instrumentation.

7 So once a month, there is a requirement that  
8 you introduce a fission chamber and measure basically  
9 the reaction rate into those. So you get a map of the  
10 power distribution in the reactor, and you have to be  
11 able to predict that before you start the reactor,  
12 what's going to happen.

13 This is high-precision measurement, and what  
14 the advantage or what we can do with that is that you  
15 can basically extract the value of the burnup in all  
16 position in this reactor. Because if you do not do  
17 that correctly, you will not be able to reproduce the  
18 power distribution.

19 So the power distribution in the reactor is  
20 very dependent of the burnup of the fuel, of the  
21 composition of the fuel in the different locations.  
22 So by taking advantage of that, and doing a lot of  
23 perturbation on sub-batches basically, we can extract  
24 information which I will briefly describe.

25 The information that we have, we have

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1 translated that information into 11 reactivity  
2 decrement benchmarks, assuming a 17 by 17 PWR reactor  
3 design.

4 So you have here basically 11 problems or 11  
5 that we're giving you here, and for each of those,  
6 each of those levels, for example, this one, we give  
7 you an exact geometry of what the result we're going  
8 to give you.

9 You for -- also then for each burnup, we are  
10 going to give you the difference in reactivity between  
11 zero burnup and 10, 20 and 60 and so on. With your  
12 code, whatever code you want to use to use in your  
13 storage or transportation cask, you can compare,  
14 because this is actually experimental value, which  
15 will tell you how well your code is going to do in  
16 comparison of those values.

17 So those are essentially measurements of  
18 criticality which are obtained on actual spent fuel,  
19 which basically contains a complement of all the  
20 nuclides in the spent fuel. Dale did a little  
21 calculation here, and what I didn't mention is that in  
22 those benchmarks, we also come up with uncertainty  
23 value, which I will not get into the discussion.

24 But the fact is that the accuracy coming  
25 from the reactor is actually extraordinary. It's

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1 very, very good. Our main uncertainty is that when we  
2 extrapolate the reactor conditions, typically a  
3 reactor will run around 300 degrees Centigrade and the  
4 fuel inside, the fuel at some higher temperature.

5 When we extrapolate the number from reactor  
6 conditions to cooled condition, this is where most of  
7 the accuracy is actually coming from.

8 But the reactor itself, when you look at the  
9 million, over a million data points, and when you're  
10 looking at over 600 flux maps coming from four  
11 different reactors, the accuracy sticks out  
12 extraordinary and it takes into account isotopic  
13 content, cross-section value and so on. So it takes  
14 a full, all the elements which are typical of a  
15 criticality analyses.

16 Dale did the quick calculations, which shows  
17 basically the bias and uncertainty coming from the  
18 methodology, which is recommended in the ISG, and you  
19 can see that basically you go between a value of about  
20 1.5 to about 3 percent between those two values. Ours  
21 is essentially constant at less than one percent.

22 This is using the same tool. The difference  
23 obviously is first of all, we involve all the elements  
24 here, rather than a limited number. But the fact is  
25 it's coming from the accuracy of the measurements that

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1 we have here, compared to the accuracy of the data  
2 that this method has to rely to.

3 As mentioned before, basically it's not  
4 straightforward to take a small piece out of a fuel  
5 rod. We basically gather representative sample and  
6 then be able to calculate what should be the  
7 conditions that prevails, so that you can make a  
8 comparison of what you calculate compared what you  
9 find there, and on top of that, you have to insert  
10 what is coming from the chemical analyses.

11 That's what is very easy to see. All you  
12 have to do is sell the same sample to three different  
13 labs, and you can be assured that you will have a  
14 variation in the number. That has been known as the  
15 Yankee Rowe data from a number of years ago, and there  
16 was a difference of 20 percent between the result of  
17 the lab coming from the same sample. So this is  
18 basically -- basically this is a given when you deal  
19 with chemical analyses.

20 So in summary, I just wanted to let you know  
21 that there are definitely a proposed alternative  
22 approach, which is relying on full burnup credit, not  
23 looking at individuals at the time, and having to  
24 assume content plus uncertainty, then cross-section  
25 and uncertainty.

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1           We certainly consider that the reactor data  
2           are experimental benchmark. Also, the reactor  
3           operators don't want to be called basically an  
4           experimental as to the process. This is the  
5           methodology which also has the advantage of being  
6           applicable to storage, transportation, disposal, wet  
7           or dry storage.

8           It basically has the beauty that it has a  
9           continuity from the reactor operator going down the  
10          chain, going into the pool, going to the cask for  
11          storage and eventually going for transportation.

12          So coming back now to transportation  
13          specifically, burnup credit is definitely a high  
14          priority topic. As mentioned, increased cask capacity  
15          for 24 we can make it to 32. We mentioned that a  
16          great percentage of the spent fuel population can be  
17          loaded.

18          Our assessment shows that there's an  
19          extremely low probability for the potential of a  
20          critical event in transportation, due to a number of  
21          factors that I've mentioned. And I will then  
22          typically, recognizing Cecil in the audience there,  
23          again that's always been our basically message, is  
24          that the conservatism is good, but at sometimes it can  
25          hurt you because you don't have only the radiological

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1 risk to consider, but also you have the non-  
2 radiological risks.

3 Often, we are worried about the damage to  
4 the cask, but in fact what we should be worried is the  
5 damage caused to the cask by something else. Thank  
6 you.

7 CHAIR RYAN: Thank you.

8 MR. MACHIELS: I have behind a number of  
9 reference, including --

10 CHAIR RYAN: We can see those in the  
11 package. Thank you very much.

12 MEMBER ARMIJO: Albert, is the industry or  
13 anyone proposing for the staff to apply this  
14 alternative approach?

15 MR. MACHIELS: We have submitted all the  
16 reports which are mentioned in the slides to the NRC,  
17 and we are waiting for -- we've basically submitted  
18 them about five, six weeks ago, and we are waiting for  
19 a response on them, in terms of whether they would be  
20 willing to review them, as well as whether they will  
21 ask for review fees, for example. But we have  
22 submitted them.

23 MEMBER ARMIJO: And this approach would be  
24 equally applicable to BWR core data as well as PWR --

25 MR. MACHIELS: The PWR, the principle is

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1 somewhat similar in way that we use the reactor. But  
2 the BWR has the advantage of cold criticals. So we  
3 would collect the cold criticals from BWR, and  
4 basically go through a similar process, and it would  
5 be actually a little bit easier for BWRs.

6 (Simultaneous speaking.)

7 MR. MACHIELS: The fuel design is a little  
8 bit more complicated, but --

9 MEMBER ARMIJO: Yes. Okay, thank you.

10 CHAIR RYAN: Welcome.

11 MR. NICHOL: Well, good morning. My name is  
12 Marc Nichol from the Nuclear Energy Institute. I  
13 appreciate the opportunity to come and speak with you  
14 today. I recognize we're behind schedule, so if I  
15 could ask, how much time do I have?

16 CHAIR RYAN: You're probably allotted 30  
17 minutes. We've got a meeting that starts just right  
18 at 12:00.

19 MR. NICHOL: Okay. I'll try to speed it up,  
20 to help us get out on time. So I would like to  
21 present today an industry perspective on burnup credit  
22 for spent nuclear fuel storage casks and transport  
23 packages, specifically on the NRC's proposed draft  
24 ISG-8 Revision 3. Also in here I'll discuss some of  
25 the comments that we had made and submitted to the

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1 NRC.

2 In general, a high level view of industry's  
3 feedback. We generally believe that Revision 3 is a  
4 significant improvement from Revision 2. I'll explain  
5 that in a little bit, although we do think that  
6 there's some opportunity for further improvements,  
7 especially through flexibility and some risk insights.

8 If you go back and look at the history of  
9 burnup credit for cask storage and transportation,  
10 it's been a little bit contentious between NRC and  
11 industry over the years, in terms of differing  
12 perspectives.

13 I think this revision of the ISG puts  
14 industry and NRC closer together in our perspectives,  
15 although I would note that if you look historically,  
16 and I've heard some of the data today, that there's  
17 only been four transport packages that have applied  
18 for burnup credit, and none of them met the previous  
19 revisions of the ISG. Burnup credit hasn't been used  
20 for cask storage.

21 I think the insight to come out of that is  
22 that the ISG, the guidance, needs to be developed with  
23 the perspective of can it be used and will it be  
24 widely implemented by industry. So from that  
25 perspective, our major comments were designed to

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1 improve the guidance, such that it results in a set of  
2 guidance that is easily adopted by industry and could  
3 widely be adopted for the future.

4 That, in my opinion, ultimately increases  
5 the value of burnup credit. Also some further  
6 background. Burnup credit is desirable by the  
7 industry. Certainly, calculating the burnup of fuel  
8 has been done from the beginning of designing the  
9 cores. So it's very well known how to do that.  
10 There's huge benefits in terms of cask storage and  
11 transportation for using burnup credit, and it  
12 assures, has reasonable assurance for adequate safety  
13 and protection.

14 And I would also note that if you look at  
15 spent fuel pool criticality, there's been decades when  
16 there's been use of burnup credit. So it's nothing  
17 new; it's just it hasn't been widely used in cask  
18 storage and transportation, and that's really where we  
19 focused, to get to that end goal, where it could be  
20 widely adopted.

21 We had five major areas of recommendations.  
22 The last four on my slide, I think the NRC has done a  
23 pretty good job of explaining how they're planning on  
24 addressing those. I don't think that there's too much  
25 contentious there.

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1 I would like to focus on burnup  
2 verification, because I think that's really where if  
3 we could see improvements, we would also likely see an  
4 improved likelihood of adoption by industry.

5 So just to highlight, the NRC has done a  
6 good job explaining the improvements, but certainly  
7 greater benefit to utilizing the burnup credit, and  
8 this is because of the inclusion of fission products  
9 and extending the range.

10 They also have -- NRC has also used more  
11 risk insights and improved the flexibility. So we  
12 commend them for doing that. In the area of burnup  
13 verification, and this is certainly industry's  
14 greatest interest for providing our comments and  
15 hoping that we can influence some improvements to the  
16 guidance, we believe that the approach for burnup  
17 verification should fundamentally start at looking at  
18 the basic concept of how do misloads happen.

19 The misload is identified as loading an  
20 assembly with a higher burnup than what was qualified  
21 for that location. So industry went back and looked  
22 at all of -- well, we looked at some of the different  
23 types of misloads that could occur, and tried to put  
24 them into buckets.

25 We identified three buckets. The first is

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1 loading the wrong fuel assembly. This is the one  
2 that's traditionally thought of picking up Assembly 1  
3 when you should have been picking up Assembly 2. So  
4 that would be the first category.

5 The second category is calculating a burnup  
6 value higher than actual. So my calculations say that  
7 this assembly is 45 gigawatt-day per MTU, when in  
8 reality it's 44. That would be the second category.

9 The third category is assigning the wrong  
10 burnup value to a fuel assembly, and I think from what  
11 I've heard today from the NRC's presentation, in  
12 identifying that a lot of the errors occur in the  
13 procedural process at the beginning, this is the  
14 category that those would fall within.

15 And so even when you identify -- after  
16 identifying these three categories, our position is  
17 that one, you should, through risk information,  
18 identify which one has the most, highest probability  
19 or consequences. Then start to look at how do you  
20 advocate for mitigative actions, such that you could  
21 prevent or preclude or mitigate those types of  
22 consequences.

23 So we believe that the guidance should take  
24 that type of a focus.

25 MEMBER SKILLMAN: Marcus, before you

1 proceed, if I go back to the example, which is Slide  
2 17 of the first presentation, in the Palisades event,  
3 it was the cooling time. In the North Anna and Surry  
4 event, it was asymmetrical decay heat limits and in  
5 Grand Gulf, it was database issues. It seems that  
6 there's a number four that needs to be on your list,  
7 and that is understanding the relationship of the  
8 characteristics of the fuel assemblies to the design  
9 requirements of the cask.

10 So I think it's more than just the wrong  
11 assembly or the burnup, or the burnup failure to the  
12 assembly, but it's understanding how that fuel  
13 assembly, whatever its burnup, presuming it's  
14 accurate, fits into the package.

15 MR. NICHOL: I agree. We intended three to  
16 cover that category, so perhaps we could go back in  
17 and rephrase number three. Number three was intended  
18 to capture those types of events, where you loaded an  
19 assembly with the wrong characteristics, or you did  
20 not identify those.

21 CHAIR RYAN: Basically, you've got a  
22 mismatch between the assembly and burnup.

23 MR. NICHOL: Mismatch, right, right. So you  
24 should have been loading an assembly with these  
25 characteristics, but somehow you loaded an assembly

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1 with different characteristics. So our intent was to  
2 include that in three.

3 MEMBER SKILLMAN: Thank you.

4 CHAIR RYAN: Okay.

5 MR. NICHOL: So when we looked at those  
6 three, we also tried to evaluate the activities or the  
7 elements to prevent a misload, that the NRC has  
8 identified and that we could think of. Largely, we  
9 identified the very same ones that the NRC did,  
10 although we had a different perspective on their  
11 roles, functions and what they actually accomplish.

12 Those three elements that I'll discuss are  
13 burnup measurement, misload analyses and admin  
14 procedures. In the draft ISG-8 used -- burnup  
15 measurement was a primary method of verification. The  
16 alternative to that was misload analysis and the  
17 defense-in-depth misload analysis was some admin  
18 procedures.

19 When we considered the function and purpose  
20 of these different things, we actually saw it a little  
21 bit differently. So we saw the admin procedures being  
22 the primary method of verification. The admin  
23 procedures are the ones that are intending to prevent  
24 misloads.

25 Now we recognize that in the current state

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1 of the procedures, that a misload is still credible.  
2 So because of that, we wanted to use misload analyses  
3 as a defense-in-depth.

4 Therefore, say using them to verify that if  
5 you did have a misload, even though you're trying to  
6 prevent the misload, if you did have a misload, that  
7 you would still remain subcritical. So that's the  
8 defense-in-depth approach we had proposed.

9 We did propose to eliminate burnup  
10 measurements. I believe burnup measurement is one of  
11 the major reasons why burnup credit in cask storage  
12 and transportation hasn't been more widely adopted,  
13 and so that we, industry does not want to do burnup  
14 measurements. That's why we recommended eliminating  
15 that.

16 I will say, going back to an earlier  
17 conversation you had on the front-loaded processes for  
18 selecting the assemblies, those are performed under QA  
19 programs and QA control. So just to clarify that  
20 point.

21 In essence, not only does industry not want  
22 to do burnup measurements because they're problematic  
23 to implement, but they're also inaccurate and we  
24 believe that they're not very effective at addressing  
25 those three types of categories.

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1           So here, we don't believe that burnup  
2 measurements address Categories 1 and 3, 3 being the  
3 one that's been identified today as perhaps the most  
4 significant. It's, in our opinion, less effective  
5 than admin procedures for addressing the second  
6 category.

7           It is widely recognized that reactor records  
8 are very accurate, typically within two percent, and  
9 that reactor records are also calibrated with in-core  
10 measurements. So in effect, that's a type of  
11 measurement. We think that provides a high level of  
12 confidence that the records that are -- the calculated  
13 burnups are very close, and we also recommend taking  
14 an uncertainty penalty on the burnup, to further do  
15 that.

16           So in our proposed administrative  
17 procedures, these were designed to address those three  
18 types of categories, and in our formal comments to the  
19 NRC, we tied them a little bit more closely. I didn't  
20 do it on this slide. Certainly verifying the identity  
21 of the fuel prior to and after closing the cask would  
22 address Category 1, loading the wrong fuel assembly.

23           Verifying burnup value from a QA record  
24 would also be, I think that would be looking at  
25 Category 2, as well as reducing the reactor record by

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1 the associated uncertainty. Verifying the fuel meets  
2 the loading criteria, number five here, that's really  
3 addressing misload Category No. 3, and that certainly  
4 is an important part.

5 As well as number six here, performing and  
6 developing all those processes and procedures,  
7 according to the QA program. We think that that's  
8 going to go a long way in preventing these, and  
9 certainly the NRC has identified some misload events.

10 I can't comment specifically on whether, on  
11 what processes and procedures they used, whether  
12 they've improved over time since those events or not.  
13 But certainly we can look into that.

14 MEMBER POWERS: But can you comment on the  
15 reliability of administrative procedures in general?

16 MR. NICHOL: I'm sorry. What was the  
17 question?

18 MEMBER POWERS: Can you comment on the  
19 reliability of administrative procedures in general?

20 MR. NICHOL: In general, they're reliable.  
21 Certainly, we agree that there are areas that could be  
22 --

23 MEMBER POWERS: I guess I'm looking for  
24 something other than an opinion. I'm looking for  
25 something, you know, that I can grab ahold of and say

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1 it's reliable to this extent.

2 MR. NICHOL: I think that we would have to  
3 do some more quantitative analysis on that, to give  
4 some type of response to that.

5 MEMBER POWERS: Well, I mean it seems like  
6 that's absolutely essential.

7 MR. NICHOL: And I would agree, that that  
8 would be very important to do, to incorporate into  
9 this guidance, to further risk-inform, to make sure  
10 that the procedures and processes that are being  
11 proposed in the guidance are the ones that are --

12 MEMBER POWERS: It seems to me your problem  
13 is that the Commission has specifically in fact asked  
14 the staff not to rely exclusively or even  
15 predominantly on administrative procedures, and here  
16 you're saying this is the key to the thing.

17 MR. NICHOL: Well, this is --

18 MEMBER POWERS: You're asking them to do  
19 something that I would approach with a certain amount  
20 of trepidation, going up and telling the Commission  
21 that --

22 MR. NICHOL: Well not necessarily, because  
23 if you go to this slide, it's the primary means of  
24 verifying, but it's not the only. We also add in the  
25 defense-in-depth with the misload analyses. So what

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1 we're saying is don't rely only on the administrative  
2 procedures.

3 Rely on them to a great extent to reduce as  
4 much as possible the potential, but also perform the  
5 misload analyses, such that if that event does occur,  
6 you're assured that it will remain subcritical.

7 MEMBER POWERS: If I do, if I make a mistake  
8 despite my procedures, or a misloaded things, what are  
9 the chances my misload analyses are going to be any  
10 use?

11 MR. NICHOL: Your misload analyses will have  
12 limited -- they will have already limited the burnup  
13 curves of the fuel, such that -- and they will have  
14 been informed by the potential for misloads. Such  
15 that that misload event would have been within an  
16 analyzed condition, and an analyzed condition that  
17 would have concluded that it's subcritical.

18 MEMBER POWERS: Okay.

19 MR. NICHOL: There are some procedures that  
20 we do not recommend. The first, verify location of  
21 high reactive fuel in the pool. This is less  
22 effective than what we've recommended, and it also  
23 requires additional resources. We don't believe that  
24 it's necessary. It could be some best practice that  
25 industry implements, but we don't believe it should be

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1 in the guidance.

2 Qualitative visual is similar, that it's not  
3 absolutely necessary. We recognize the NRC has  
4 proposed an alternate to this, to do one or the other.  
5 That could be acceptable, and since qualitative is not  
6 very resource-intensive.

7 The condition for no fresh fuel in the pool  
8 would duplicate the qualitative one. It would  
9 mitigate the consequences, but we're proposing to  
10 mitigate the consequences through the misload  
11 analysis, to have that condition analyzed and bounded.

12 A requirement for not having fresh fuel in  
13 the pool could be problematic, if such a situation  
14 arose, where the risk fresh fuel and the utility does  
15 need to load a cask. There would be a very difficult  
16 position.

17 The pool inventory audit mentioned that this  
18 duplicates some other regulations, and should not be  
19 necessary. Now on the topic of independent third  
20 party verification, the question is not whether this  
21 should be performed or not. We agree this should be  
22 performed.

23 The question is whether it should be in NRC  
24 guidance, or whether it should be an industry-  
25 initiated best practice, which is currently performed

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1 now. So all of the -- the utilities that I've talked  
2 to do perform independent third party verification as  
3 part of their best practices. So --

4 MEMBER ARMIJO: At what point in their  
5 process? In the selection of the fuel to be --

6 MR. NICHOL: My understanding, it's the  
7 entire process, from the very first selection of the  
8 fuel, all the way through the end. Now --

9 MEMBER ARMIJO: But somehow at least in the  
10 three examples that we were presented this morning,  
11 those processes are independent, but they don't really  
12 help.

13 MR. NICHOL: Yeah, and that's why I can't  
14 comment specifically on those, because I haven't  
15 researched them. But it's possible that this third  
16 party verification came about afterwards. Possible.  
17 I wouldn't know, but we could certainly investigate  
18 those to find out why they occurred and how they could  
19 have been prevented.

20 MEMBER ARMIJO: Yeah. I want to make sure  
21 I understood what you were saying about the misload  
22 analysis. Is it the NEI position that the misload  
23 analysis would be done with fresh fuel, since you're  
24 not going to verify that there's no fresh fuel in the  
25 pool?

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1 MR. NICHOL: Yeah. Let me get to that.  
2 Yeah, that would certainly be one. So the misload  
3 analysis for the single misload would be a fresh fuel  
4 assembly, because you would have a condition that  
5 would allow fresh fuel in the pool.

6 We recognize, and also we -- well, we  
7 recognize for both of our proposed assumptions for the  
8 misloads that they're extremely conservative, and the  
9 NRC pointed that out. We didn't have sufficient time  
10 to come up with something that is both simple and a  
11 little bit less restrictive.

12 Certainly, the industry desires something  
13 that's easy to implement. Some of the proposals where  
14 you have to verify 90 percent, you have to verify your  
15 spent fuel pool inventory according to some  
16 assumptions, could be rather intensive and difficult  
17 to implement, as well as in the general cask design,  
18 it has to encompass all of the potential sites.

19 If you do that, that's rather restrictive.  
20 If you start to allow it to be site-specific, you get  
21 into an area where you may be -- it may result in  
22 multiple amendments to that cask --

23 (Simultaneous speaking.)

24 CHAIR RYAN: Another thing, you've got a  
25 variety of plants that exist in the United States,

1 more on the way, and over a 30 year or 60 year  
2 lifetime. They're going to be different.

3 MR. NICHOL: They're going to be different,  
4 and --

5 CHAIR RYAN: So saying that they can all be  
6 kind of cookie cutter doesn't seem to be smart.

7 MEMBER ARMIJO: Oh, it's a penalty that the  
8 industry would pay if they do it this way.

9 MR. NICHOL: Right, right. Yeah. It would  
10 be a penalty. Also, there's going to be future fuel  
11 that's discharged, and you're going to have to verify  
12 that the future fuel is encompassed in the old  
13 assumptions. Not that it could not be a valuable  
14 option. I believe it's conservative. I think it  
15 could be viable, but industry would desire something  
16 that's a little bit more simple to implement.

17 CHAIR RYAN: But it's not a simple problem  
18 you're trying to solve. There's a lot of variation  
19 within the problem, based on specifics we're given,  
20 right?

21 MR. NICHOL: No. There are a lot of  
22 variations in the specifics of the plant. But the  
23 cask, when it's approved, should be all-encompassing  
24 of the sites. If it is and it's overly-restrictive,  
25 then certain sites are going to request the vendor to

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1 have a special amendment just for their fuel.

2 You get into a condition where there are so  
3 many amendments or potential for exemptions. So what  
4 industry would like is a streamlined process that's  
5 very simple to implement, but is not too restrictive.

6 Now I agree, that the answer may be in  
7 between what NRC and industry is proposing. Perhaps  
8 this is something that needs more effort to come up  
9 with a reasonable solution.

10 CHAIR RYAN: That's the sense I'm getting.  
11 It's a pretty wide playing field. I don't know how  
12 you get there with one answer, without having a range  
13 of possibilities within that answer.

14 MR. NICHOL: Yeah. Certainly from our  
15 perspective, we have not been able to put a lot of  
16 thought into how you could streamline this and not be  
17 overly-restrictive. But there could be a solution out  
18 there, and perhaps that's needed. More time is needed  
19 to find that.

20 MEMBER SKILLMAN: I guess I'm alarmed from  
21 the perspective that a number of years ago, there was  
22 an airplane accident, and what had happened is they  
23 refueled a gas turbine jet airplane with piston engine  
24 octane 100 fuel. Then the plane crashed and killed a  
25 bunch of people.

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1           There has never been another incident like  
2           that. Somehow the airline industry realized that  
3           segregation of fuel types of critical. So while I  
4           appreciate what might be considered to be a making  
5           easier a requirement by those procedures not  
6           recommended on page seven.

7           We ought to be doing both. We ought to be  
8           making sure that the administrative procedures are so  
9           robust, and maybe more importantly, that the people  
10          that are handling the fuel really get it. So the  
11          procedures, so the process and procedures are  
12          restrictive is not the word I would choose, but are  
13          accountable enough that the likelihood of a misload is  
14          down in the grass.

15          Then on top of that, do the misload analysis  
16          to further reduce the likelihood of an event.

17          CHAIR RYAN: Doing a misload analysis really  
18          gives you, you know, what's the consequence, not what  
19          the likelihood is.

20          MEMBER SKILLMAN: Well, I'm going for  
21          prevent it, prevent it right in the front end of the  
22          dialogue, and it seems to me that industry ought to be  
23          saying you know what? This is one that's worth  
24          investing in, because it protects everybody.

25          MR. NICHOL: Which one was that?

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1 MEMBER SKILLMAN: Some combination of the  
2 ones on page seven.

3 MR. NICHOL: On page seven?

4 MEMBER SKILLMAN: And clearly, as you have  
5 well pointed out, industry has great interest in  
6 ensuring that new fuel doesn't find its way into a  
7 cask, because that is a huge investment, and they  
8 would like to have as little SWUs going out the doors  
9 as economically appropriate.

10 But it seems that there ought to be kind of  
11 a mentality that says a couple of these, you have  
12 visual and others, might be worth their investment.

13 MR. NICHOL: We agree that some of these are  
14 very worthwhile, and as I mentioned, independent third  
15 party is already ongoing. The question is whether it  
16 should be in the NRC guidance, or whether it should be  
17 industry best practice. I think that could be, you  
18 know, discussed in great detail.

19 CHAIR RYAN: But sadly we don't have time  
20 for it this morning.

21 MR. NICHOL: Right.

22 CHAIR RYAN: So press on.

23 MR. NICHOL: Okay. In terms of depletion  
24 validation flexibility, I won't go into too great of  
25 a detail here, but certainly Albert from EPRI

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1 presented on an alternative to the Oak Ridge method.  
2 We recognize the Oak Ridge method is overly  
3 conservative, and it is due to the measurement  
4 uncertainties. I think you heard a little bit about  
5 that today.

6 So there could be other methods out there  
7 that aren't as restrictive. So certainly flexibility  
8 in the guidance to accommodate potential future  
9 methods would be efficient from that standpoint. I  
10 think the NRC did a good job of addressing these  
11 comments in their presentation.

12 So here are my conclusions. So of course  
13 Revision 3 is a significant improvement. However, we  
14 believe that further improvements to the guidance  
15 could result in greater efficiency and effectiveness.  
16 Certainly industry has a great interest in having  
17 guidance that we would desire to widely adopt, and  
18 from that perspective, we hope that there's due  
19 consideration of our perspectives. Thank you.

20 CHAIR RYAN: Thank you very much, Marcus.  
21 I appreciate you being here. Any comments, Jack?

22 MEMBER SIEBER: No, I don't think so. I  
23 think the presentations were pretty well. I do favor  
24 some of the industry comments, like in-pool  
25 measurements as not being as helpful as it might be

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1 because of uncertainty. Otherwise, everyone did well.

2 CHAIR RYAN: Thank you very much. Dana?

3 MEMBER POWERS: Yeah. I think the  
4 presentations were superb, and I especially appreciate  
5 Mr. Machiels?

6 MR. NICHOL: Machiels.

7 MEMBER POWERS: Machiels' comments about  
8 making it operationally simpler, where the guidance is  
9 fairly complicated. But I think I agree with Dick.  
10 Let's do a belt and suspenders approach here, because  
11 this is a mistake you just don't want to have, from  
12 all our perspectives.

13 Being able to do it so that it remains  
14 operational and flexible is really an excellent goal.  
15 But reliance on administrative limits is a problem for  
16 the staff, just because the guidance the Commission  
17 has given in connection with defense-in-depth  
18 regulatory philosophy.

19 You cannot do that. I mean I wouldn't want  
20 to be the staff going to the Commission to focus on  
21 administrative limits, in the face of that kind of  
22 guidance, without a lot of body armor. I mean it's  
23 just a problem for them, because five great Americans  
24 have told them don't rely exclusively or even  
25 primarily on administrative limits to the extent

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1 possible.

2 So it's just a problem. So you've got to  
3 give them armor to go make that pitch, wherever,  
4 wheresoever they choose to make it.

5 CHAIR RYAN: Thank you. Sam?

6 MEMBER ARMIJO: Yeah. I agree with the  
7 prior comments. I think the Revision 3 is a huge  
8 improvement. I compliment the staff, Oak Ridge and  
9 everyone who worked on it. I think burnup credit,  
10 full burnup credit, you probably will never be able to  
11 get it unless you take an approach similar to what  
12 Machiels has proposed.

13 Whether you really get much by having the  
14 full burnup credit versus this actinides plus a  
15 certain set of fission products, whether there's  
16 really much benefit there, I don't know. But you  
17 know, I can see that as a next step in this type of  
18 analysis.

19 I think this has been a lot of progress and  
20 good work. Thank you.

21 CHAIR RYAN: Thank you, Sam. Dick.

22 MEMBER SKILLMAN: I do. I thank the staff  
23 and EPRI for the presentations. They were thorough,  
24 they were crisp, they were clear, well-done. I would  
25 like to recognize Mr. Machiels' comment in balancing

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1 the risk between burnup credit, what is gained, and  
2 the transportation risks.

3 I think that's a very important point that  
4 needs to be clear in everyone's lenses. I'm going to  
5 settle on this idea that the process has to carry the  
6 day.

7 After all the data's completed, after  
8 everyone's, after the engineers and the physicists  
9 have said by golly, we know the k-effective is less  
10 than .95 or whatever the number is, there still needs  
11 to be a robust process that prevents an inadvertent  
12 misload, that results in an event.

13 It seems to me that we found a way to do  
14 that in so many other places in the industry, and so  
15 many other places in operating these plants. There's  
16 no reason why we can't insist on that same level of  
17 accountability and integrity on this piece of our  
18 processes.

19 CHAIR RYAN: Harold.

20 MEMBER SKILLMAN: Dr. Ryan, thank you.

21 CHAIR RYAN: Thank you.

22 MEMBER RAY: Yeah. I just think there's  
23 maybe too much emphasis on efficiency without the kind  
24 of rigor that I think everybody else has expressed  
25 here, in terms of ensuring that an event is avoided,

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1 because the delta efficiency being achieved by not  
2 doing some things that can be done is very small.

3 CHAIR RYAN: I agree. Let me first thank  
4 the presenters for that. I think it's been a very,  
5 very good meeting and it, I think, summarizes a lot of  
6 work by Meraj, you and your staff and your consultants  
7 and contractors.

8 I think as all the members have expressed,  
9 we've gotten an awful lot out of today's briefing. So  
10 thank you all very much for your hard work, and coming  
11 today to present it to us.

12 On the technical points, I think I agree  
13 with the way that several colleagues have expressed  
14 it, and Dick in particular, that you know, it really  
15 should not be something because it's a little bit  
16 faster and the risks are low.

17 That's how we get in trouble, and I think we  
18 have to say things that, you know, we have to be  
19 rigorous, whether we think there's a chance that  
20 something could happen or not.

21 So I share those kind of sentiments, that we  
22 really ought to maintain the rigor of how we approach  
23 these things, even though they may be off. I was  
24 taken by the slide that showed that the  
25 misidentification chart led to a lot of problems or a

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1 number of problems, more than any other route down  
2 that event tree.

3 So that stuck with me as sort of the watch  
4 word there. While we have to balance, we sure have to  
5 recognize that we have to err on the side of safety  
6 and conservatism about accepting by faith or some  
7 other method that things won't happen just because  
8 we're doing a better job.

9 So I think with that, if there are no other  
10 comments, we shall -- sir?

11 DR. LANCASTER: Are you asking for  
12 comments?

13 CHAIR RYAN: Yes. We have just a very short  
14 time, because we're ten minutes over.

15 DR. LANCASTER: Right. I just want to be  
16 very quick about this.

17 CHAIR RYAN: Just for the record, identify  
18 yourself?

19 DR. LANCASTER: Oh, I'm Dale Lancaster,  
20 Nuclearconsultants.com. I just want to make it clear,  
21 because some of the comments here, I think, may have  
22 missed something. A misload does not create an event,  
23 because if you miss -- we've been talking about PWR  
24 burnup credit.

25 The spent fuel pools have significant

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1 dissolved boron, soluble boron that would prevent a  
2 criticality in any misload event in the pool. So  
3 that's the Case 1. So misload doesn't cause a problem  
4 there.

5           These casks are then dried, again in order  
6 -- if there was a misload, then you would have to  
7 flood these casks in order to get an event. So again,  
8 I think the primary answer is we are not relying on  
9 administrative procedures to prevent an event.

10           We're relying on administrative procedures  
11 to prevent one possible way of getting to an event.

12           CHAIR RYAN: That's the way I took it. It  
13 was one possible route. So I appreciate your  
14 thoughts. Thank you for that clarification. Raj, any  
15 last words or we're good?

16           MR. RAHIMI: I cannot go without rebuttal.

17           CHAIR RYAN: Well, don't rebut.

18           MR. RAHIMI: Okay. Meraj Rahimi, NRC.  
19 Again, these casks, we certify these casks that could  
20 be loaded in fresh water. No boron credit for these  
21 transportation casks. Once we certify these casks,  
22 they can be loaded, unloaded, even at the non-reactor  
23 site, non-borated pool. So that's what we use these  
24 casks for.

25           CHAIR RYAN: Thank you, Raj. With that and

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1 hearing all the comments from members of staff, we'll

2 --

3 MEMBER POWERS: And from the public.

4 CHAIR RYAN: Any members of the public? Is  
5 the bridge line open?

6 (No response.)

7 MR. BROWN: I never heard a beep, so I don't  
8 think anyone has called in.

9 CHAIR RYAN: No, I don't think we had  
10 anybody on the bridge line. Any other comments from  
11 members of the public, participants in the audience?

12 MR. BROWN: Mike, we'll get back to Drew on  
13 how to prepare for the full Committee on what --

14 CHAIR RYAN: Yeah, that will be fine. Yeah,  
15 we'll talk after the briefing about that. Anything  
16 else?

17 (No response.)

18 CHAIR RYAN: Hearing nothing else, the  
19 meeting's adjourned.

20 (Whereupon, at 12:10 p.m., the meeting was  
21 adjourned.)

22

23

24

25

CERTIFICATE

This is to certify that the attached proceedings  
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# **Interim Staff Guidance 8, Revision 3 – *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks***

**Presentation to the Advisory Committee on Reactor  
Safeguards Subcommittee on Radiation Protection  
and Nuclear Materials**

**July 10, 2012**

# Agenda

Item	Topic	Presenter(s)	Time
1	Opening Remarks and Objectives	Dr. Michael Ryan, ACRS	8:30 – 8:35 a.m.
2	Staff Opening Remarks	Meraj Rahimi, NMSS	8:35 – 8:45 a.m.
3	Changes to ISG-8	Drew Barto, NMSS	8:45 – 9:00 a.m.
4	Cask Misload Probability	Brian Wagner, RES	9:00 – 9:30 a.m.
5	Burnup Credit Code Validation	Dr. John Wagner, ORNL	9:30 – 10:00 a.m.
6	Break		10:00 – 10:15 a.m.
7	Public Comments and Proposed Resolution	Drew Barto, NMSS	10:15 – 10:45 a.m.
8	Industry Efforts on Burnup Credit	Dr. Albert Machiels, EPRI	10:45 – 11:15 a.m.
9	Industry Perspective on ISG-8	Marcus Nichol, NEI	11:15 – 11:45 a.m.
10	Committee Discussion	Dr. Ryan, ACRS	11:45 a.m. – 12:00 p.m.
11	Adjourn		12:00 p.m.

## Background

- Radiation and heat were the primary design drivers for older generation of transportation packages which were designed for short cooling times
- Sub-criticality became one of the primary design drivers for new generation of high-capacity casks for longer cooled fuel

## Background (cont.)

- To achieve high-capacity, cask designers eliminated flux traps (i.e. spacing between fuel) which are needed for the Fresh Fuel assumption, and relied on Burnup Credit instead
- Burnup Credit is credit for reduction in reactivity that occurs with fuel burnup due to the net reduction of fissile nuclides and the production of actinide and fission-product neutron absorbers

## Background (cont.)

- Based on available data in 2002, staff issued guidance on taking credit for the major actinide isotopes.
- In 2007, SRM SECY-07-0815 stated:  
“... staff should focus its effort on using burnup credit as a means to insert more realism into spent fuel transportation cask criticality analyses.”

## Background (cont.)

- In 2008, letter from ACNWM to Chairman Klein stated:
  - “... recommends that the staff take a risk-informed approach to evaluating Burnup Credit, including consideration of realistic and credible scenarios, probabilities, and consequences.”
- In May 2012, staff issued draft ISG 8, Rev.3, for public comment. This ISG provides guidance for taking credit for actinides and fission products

## Major changes to ISG-8

- Credit for minor actinides and fission products
- Extend credit up to 60 GWd/MTU assembly-average
- Provide option for misload analysis with additional administrative loading procedures in lieu of burnup measurement

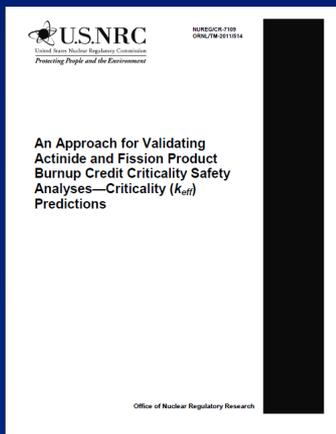
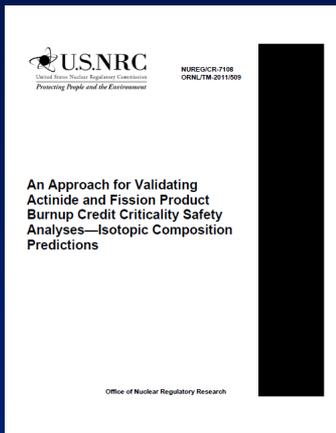
## Expanding Technical Basis for Burnup Credit

- NUREG/CR-6979, *Evaluation of the French Haut Taux de Combustion (HTC) Critical Experiment Data* (2008)
- NUREG/CR-7012, *Uncertainties in Predicted Isotopic Compositions for High Burnup PWR Spent Nuclear Fuel* (2011)
- NUREG/CR-7108, *An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Isotopic Composition Predictions* (2012)
- NUREG/CR-7109, *An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Criticality ( $k_{eff}$ ) Predictions* (2012)

## ISG-8 Revision 3 – Code Validation

- Availability of French HTC actinide data gives greater degree of confidence in actinide criticality validation than existed at the time ISG-8, Rev. 2 was published
- New chemical assay data expands the available database for fission product depletion validation and extends the range of applicability to higher burnups
- All available data used in NUREG/CR-7108 and -7109 to develop alternative isotopic depletion and criticality code validation methodologies.
- ISG-8, Revision 3 recommends crediting both actinides and fission products for up to 60 GWd/MTU

# ORNL NUREG/CRs



- Work performed under joint contract (SFST/NRR/NRO) through RES
- New isotopic depletion code validation methodologies and reference bias and bias uncertainty values
- New minor actinide and fission product criticality code validation methodology and reference bias value
- Provides recommendations regarding the use of the reference values, and the use of methodologies developed in the NUREG/CRs

## ORNL NUREG/CRs

- Applicant may use the reference bias and bias uncertainty numbers developed by ORNL in lieu of an explicit depletion or minor actinide and fission product criticality validation, provided:
  - the same code and cross section data are used in the applicant's analysis
  - the applicant's storage or transportation system is demonstrated to be similar to that evaluated in the NUREG/CRs
- Applicant should perform traditional criticality code validation for major actinides using MOX and HTC data

# Code Validation – ISG-8, Revision 3

	<b>Major Actinides</b>	<b>Minor Actinides and Fission Products</b>
<b>Criticality Analysis</b>	Applicant can perform analysis with Fresh UO <sub>2</sub> , MOX, & HTC experiments	Use ORNL-supplied bias number
<b>Isotopic Depletion Analysis</b>	Use ORNL-supplied number, or use ORNL-developed validation methodologies	

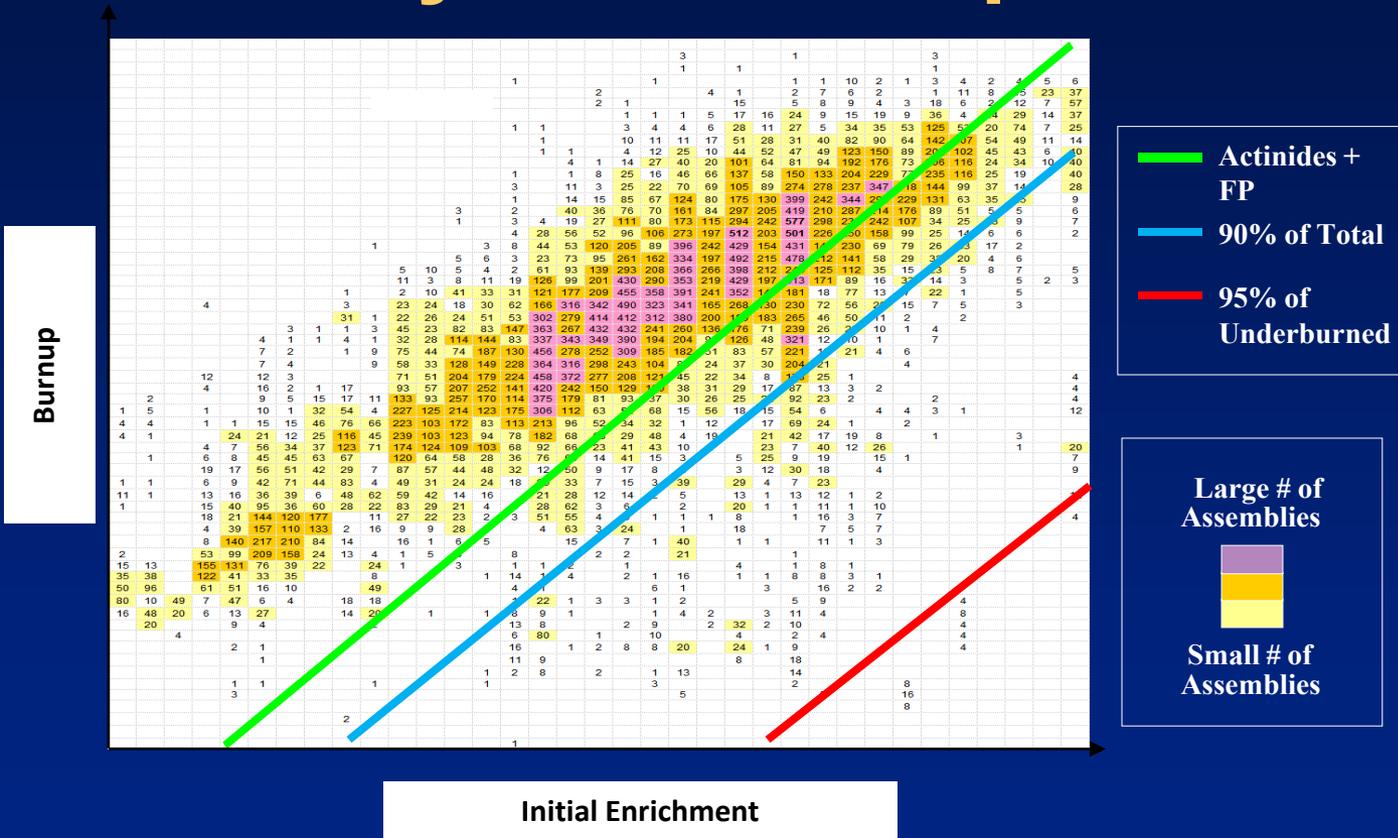
## **ISG-8 Revision 3 – Burnup Measurements**

- NUREG/CR-6955, “Criticality Analysis of Assembly Misload in a PWR Burnup Credit Cask” (2008)
- NUREG/CR-6988, “Review of Information for Spent Nuclear Fuel Burnup Confirmation” (2009)
- RES report: *Estimating the Probability of Misload in a Spent Fuel Cask* (2011)
- ISG-8 modified to allow misload analysis combined with additional administrative procedures in lieu of direct measurement

## Misload Analyses

- Single *severely* underburned misload, chosen such that reactivity bounds 95% of the underburned fuel population with 95% confidence
- Multiple *moderately* underburned misloads, chosen such that half the cask is filled with a fuel assembly that bounds the reactivity of 90% of the total discharged fuel population
- Reduced administrative margin ( $\Delta k_m \geq 0.02$ )
- Additional administrative procedures, such as ensuring no fresh fuel in pool at time of loading, or independent, third party reviews of cask loading

# Misload Analysis Fuel Population



From the 2002 EIA RW-859 Fuel Database

## Misload Report

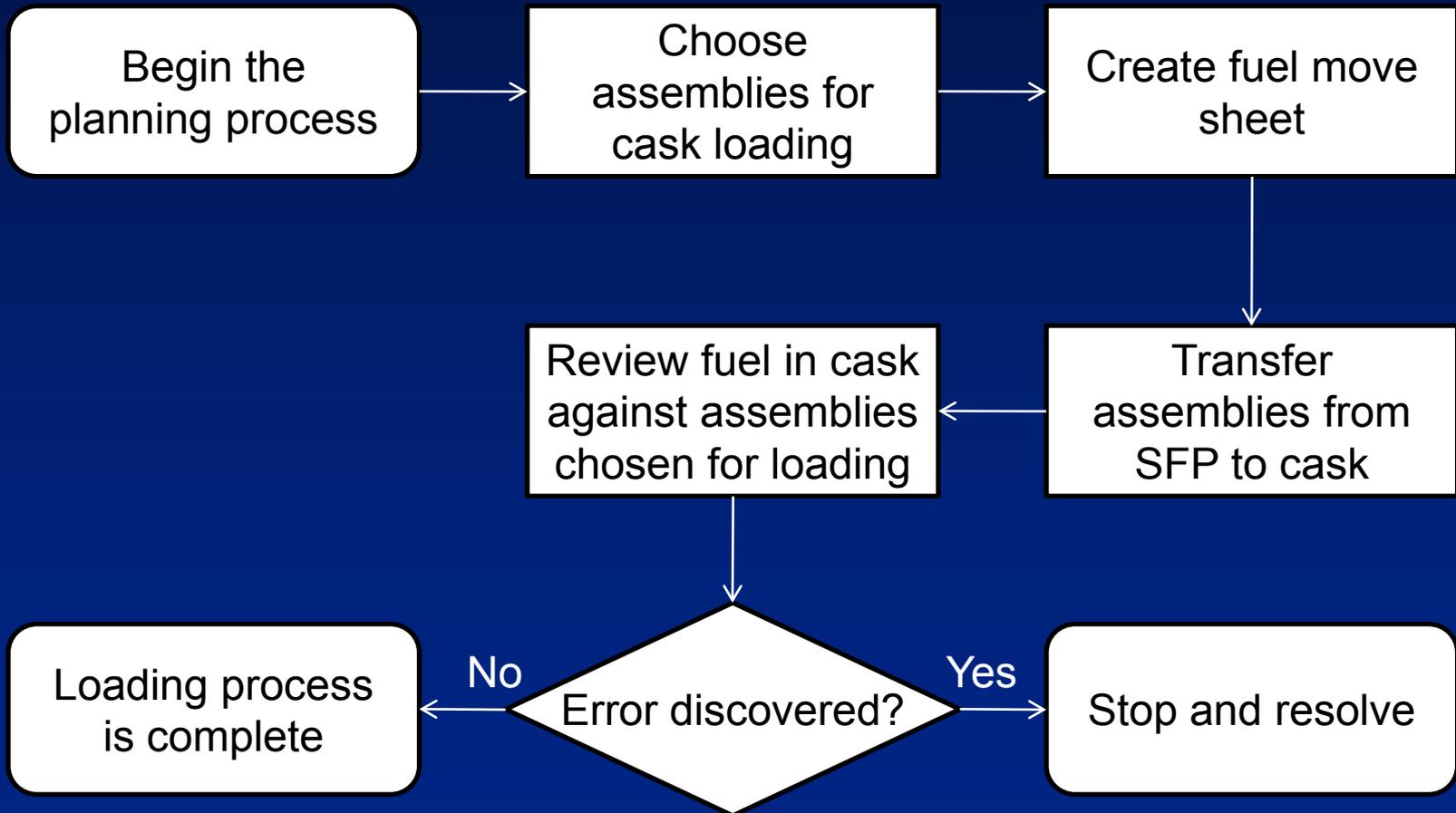
- Reviewed cask misload events to determine underlying causes and to identify common failure modes
- Calculated the probability of single or multiple cask misloads using two separate methods
  - Empirically from actual misload data
  - Using an event tree model
- Considered impact of burnup on misload probability

# Misload Events

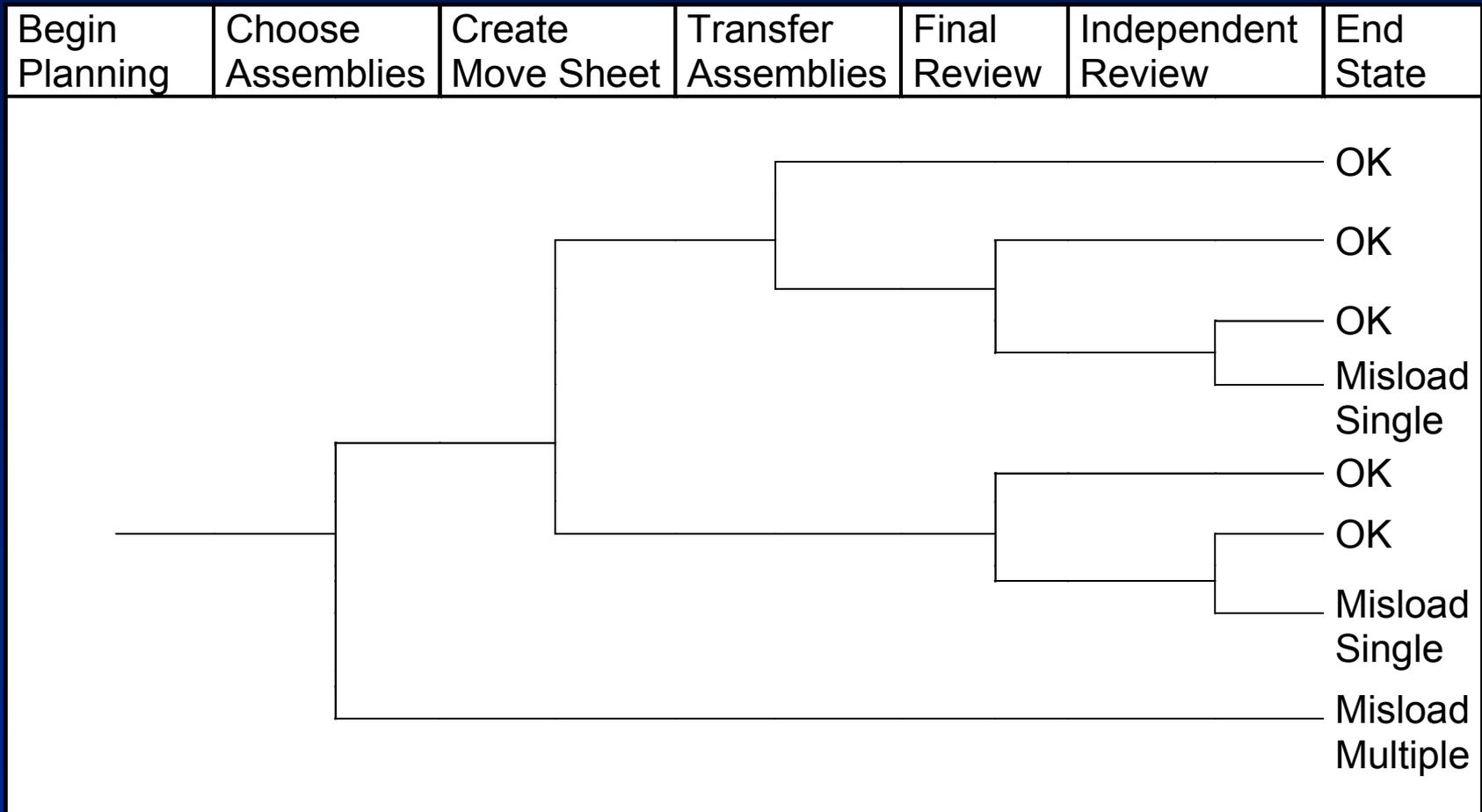
- **Palisades:** Calculation for cooling time was based on planned loading date, was not updated when loading date changed. 5 casks, 11 assemblies misloaded.
- **North Anna & Surry:** Cask design allowed for asymmetrical decay heat limits. Written procedures did not adequately explain this requirement leading to repeated errors. 11 casks, ~19 assemblies misloaded.
- **Grand Gulf:** Improper use of database containing incomplete information led to loading of assemblies exceeding allowed decay heat. 4 casks, 34 assemblies misloaded
- **McGuire (near misload):** Crane picked up incorrect assembly adjacent to the correct assembly. Error caught while assembly was being lowered

Total of 20 casks misloaded out of 1200 →  $\sim 10^{-2}$  per cask

# Cask Loading Process



# Event Tree



## Event Tree Model Details and Insights

- Empirical SFP data used for fuel transfer errors, human error probabilities from THERP used for other values
- Multiple misload event is dominant sequence
  - Multiple reviews limits the potential for single misload events
  - Multiple misload events reflect fundamental misunderstanding of cask requirements or error in procedures, database, etc and are therefore harder to catch with a review

## Misload Conclusions

- Misload events are credible
  - Empirical probability: 20 misloads / 1200 casks loaded  $\approx 10^{-2}$  per cask
  - Event Tree Model probability  $\approx 10^{-3}$  per cask
- Based on event tree model and empirical data, misloads are most likely caused by errors in the planning process
- Event is likely to involve multiple assemblies and casks

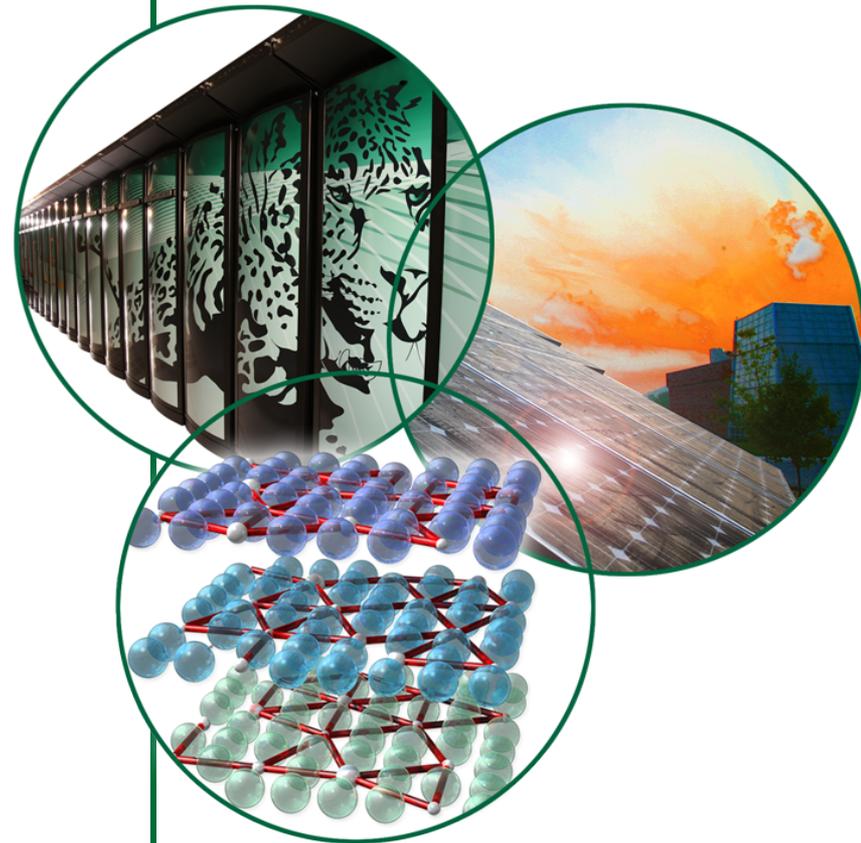
# BURNUP CREDIT CODE VALIDATION

**Presenter:** John C. Wagner

**Key Personnel:** J.M. Scaglione,  
D. E. Mueller, B.J. Marshall (criticality);  
G. Radulescu, I. Gauld, G. Ilas  
(depletion)

*Presentation to the Advisory Committee on  
Reactor Safeguards Subcommittee on  
Radiation Protection and Nuclear Materials*

10 July 2012



# Outline

- Background and Purpose
- Depletion Validation NUREG/CR-7108
  - Approach
  - Reference numbers
  - Recommendations
- Criticality Validation NUREG/CR-7109
  - Approach
  - Reference numbers
  - Recommendations
- Closure



NUREG/CR-7108  
ORNL/TM-2011/509

**An Approach for Validating  
Actinide and Fission Product  
Burnup Credit Criticality Safety  
Analyses—Isotopic  
Composition Predictions**



NUREG/CR-7109  
ORNL/TM-2011/514

**An Approach for Validating  
Actinide and Fission Product  
Burnup Credit Criticality Safety  
Analyses—Criticality ( $k_{\text{eff}}$ )  
Predictions**

Office of Nuclear Regulatory Research

# Background

- **Most significant challenge to expanded burnup credit has been the validation of depletion and criticality calculations**
  - **In particular, the availability and use of applicable measured data, especially for fission products**
- **Applicants and regulatory reviewers have been constrained by both a paucity of data and a lack of clear technical basis or approach for use of the data**
- **Rationale for restricting ISG-8, Rev. 2, to actinide-only was based on limitations in available validation data at the time**

# Purpose

- **Establish technically sound validation approaches for spent nuclear fuel (SNF) criticality safety evaluations based on best-available data and methods**
- **Apply the approaches to representative SNF storage and transportation configurations/conditions to demonstrate their usage and applicability and provide reference results**
- **Document the validation approach, its technical basis, and its application**

# Depletion Validation Technical Approach

- **Bias and uncertainty in predicted fuel isotopic compositions based on comparison to measured isotopic compositions from destructive radiochemical assays (RCA)**
- **Monte Carlo (MC) uncertainty sampling method used to estimate the bias and uncertainty in  $k_{eff}$  due to the bias and uncertainty in the predicted isotopic compositions**
  - **Additional analyses using the direct-difference method and S/U techniques**
- **Bias and uncertainty in  $k_{eff}$  determined for representative PWR transportation/dry storage cask with SCALE 6.1 and ENDF/B-VII data**
- **Sensitivity of bias and uncertainty in  $k_{eff}$  to relevant parameters was evaluated**

# RCA Data (100 PWR fuel samples )

Reactor	Measurement Laboratory	Experimental Program	Assembly Design	No. of Samples/ Fuel Rods	Enrichment (wt % <sup>235</sup> U)	Burnup (GWd/MTU)
Trino Vercellese	Ispra, Karlsruhe	JRC	15 × 15	15/5	2.72, 3.13, 3.897	7.2–17.5
	Ispra, Karlsruhe	JRC	15 × 15	16/5	3.13	12.9–25.3
Obrigheim	Ispra, Karlsruhe	JRC	14 × 14	10/6	3.00	17.1–37.5
	ITU, IRCh, WAK, IAEA	ICE	14 × 14	5/5	3.13	27.0–29.4
H. B. Robinson-2	PNNL	ATM-101	15 × 15	4/1	2.561	16.0–31.7
Turkey Point-3	Battelle-Columbus	NWTS	15 × 15	5/1	2.556	30.5–31.6
Calvert Cliffs-1	PNNL, KRI	ATM-104	14 × 14	3/1	3.038	27.4–44.3
	PNNL	ATM-103	14 × 14	3/1	2.72	18.7–33.2
	PNNL, KRI	ATM-106	14 × 14	3/1	2.453	31.4–46.5
Takahama-3	JAERI	JAERI	17 × 17	13/3	2.63, 4.11	17.4–46.2
TMI-1	ANL	DOE YMP	15 × 15	11/1	4.013	44.8–55.7
	GE-VNC	DOE YMP	15 × 15	8/3	4.657	22.8–29.9
Gösgen	SCK•CEN, ITU	ARIANE	15 × 15	3/2	3.5, 4.1	29.1–59.7
GKN II	SCK•CEN	REBUS	18 × 18	1/1	3.8	54.1

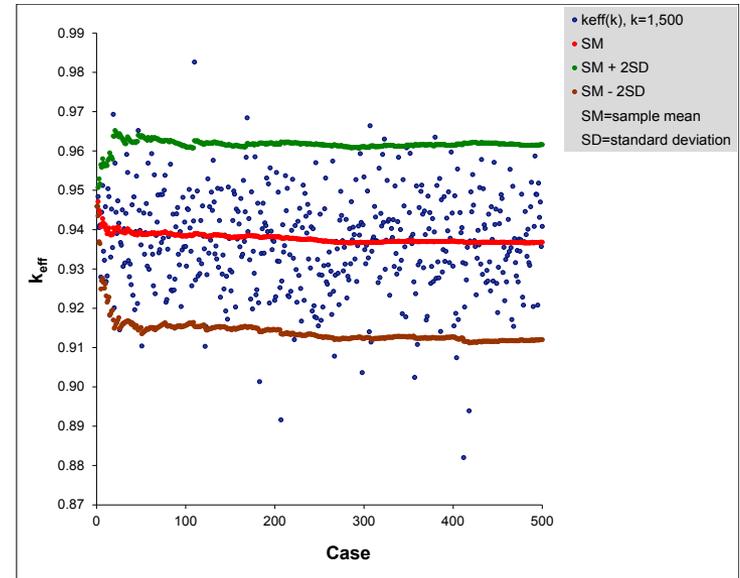
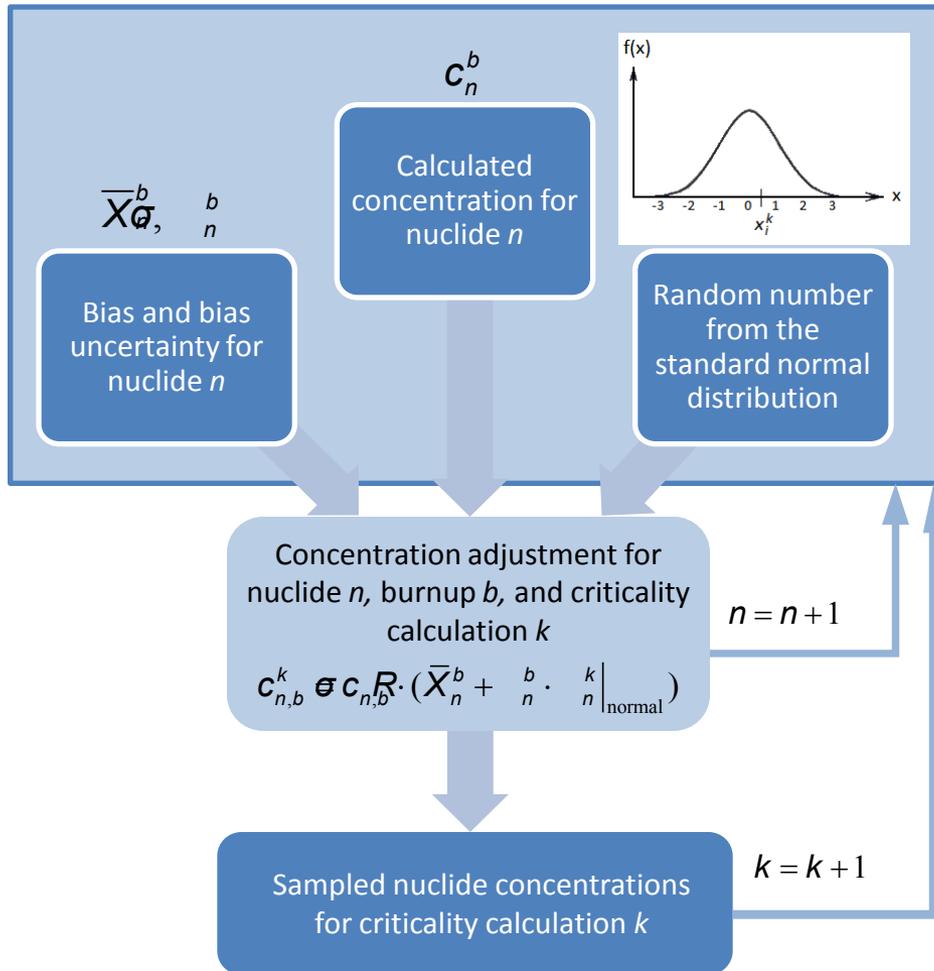
# PWR RCA Data for Burnup Credit Nuclides

Isotope	No. of samples	Enrichment range (wt% <sup>235</sup> U)	Burnup range (GWd/MTU)	Isotope	No. of samples	Enrichment range (wt% <sup>235</sup> U)	Burnup range (GWd/MTU)
<sup>234</sup> U	63	2.453–4.657	7.2–59.7	<sup>101</sup> Ru	15	3.5–4.1	31.1–59.7
<sup>235</sup> U	100	2.453–4.657	7.2–59.7	<sup>103</sup> Rh	16	2.453–4.1	31.1–59.7
<sup>236</sup> U	85	2.453–4.657	12.9–59.7	<sup>109</sup> Ag	14	3.5–4.1	44.8–59.7
<sup>238</sup> U	100	2.453–4.657	7.2–59.7	<sup>133</sup> Cs	7	3.038 – 4.1	27.4–59.7
<sup>237</sup> Np	44	2.453–4.657	16.0–59.7	<sup>143</sup> Nd	44	2.453–4.657	16.0–59.7
<sup>238</sup> Pu	85	2.453–4.657	12.9–59.7	<sup>145</sup> Nd	44	2.453–4.657	16.0–59.7
<sup>239</sup> Pu	100	2.453–4.657	7.2–59.7	<sup>147</sup> Sm	32	2.453–4.657	23.7–59.7
<sup>240</sup> Pu	100	2.453–4.657	7.2–59.7	<sup>149</sup> Sm	28	3.5–4.657	23.7–59.7
<sup>241</sup> Pu	100	2.453–4.657	7.2–59.7	<sup>150</sup> Sm	32	2.453–4.657	23.7–59.7
<sup>242</sup> Pu	99	2.453–4.657	7.2–59.7	<sup>151</sup> Sm	32	2.453–4.657	23.7–59.7
<sup>241</sup> Am	47	2.453–4.657	17.1–59.7	<sup>152</sup> Sm	32	2.453–4.657	23.7–59.7
<sup>243</sup> Am	48	2.63–4.657	17.1–59.7	<sup>151</sup> Eu	21	3.5–4.657	23.7–59.7
<sup>95</sup> Mo	15	3.5–4.1	31.1–59.7	<sup>153</sup> Eu	27	2.453–4.657	23.7–59.7
<sup>99</sup> Tc	25	2.453–4.1	16.0–59.7	<sup>155</sup> Gd	27	2.453–4.657	23.7–59.7

# MC Uncertainty Sampling Method

- Used to propagate isotopic bias and uncertainty to  $k_{\text{eff}}$
- Provides an estimate of the bias and uncertainty in  $k_{\text{eff}}$  due to bias and uncertainty associated in the predicted fuel compositions
- Provides a realistic safety margin by allowing compensating positive and negative effects of isotopic bias on reactivity
- Enables depletion code validation directly with safety analysis models
- Not sensitive to the limited number of nuclides measured in individual fuel samples

# MC Uncertainty Sampling Method Schematic



$k_{\text{eff}}$  mean and standard deviation

B&BU in  $k_{\text{eff}}$  based on the upper limit of the one-sided tolerance interval for 95% of the population and 95% confidence

# Reference Numbers

- Combined isotopic  $k_{eff}$  bias and bias uncertainty for the representative PWR SNF system model using ENDF/B-VII data

	Actinides Only	Actinides and Fission Products
Burnup (GWd/MTU)	$\Delta k_i$	$\Delta k_i$
0-5	0.0145	0.0150
5-10	0.0143	0.0148
10-18	0.0150	0.0157
18-25	0.0150	0.0154
25-30	0.0154	0.0161
30-40	0.0170	0.0163
40-45	0.0192	0.0205
45-50	0.0192	0.0219
50-60	0.0260	0.0300

# Recommendations

- ISG-8, Rev. 3, provides several methodologies that are considered acceptable for isotopic depletion validation
- In lieu of an explicit validation, the applicant may use the combined bias and bias uncertainty ( $\Delta k_i$ ) values estimated in NUREG/CR-7108. These values may be used directly, provided that:
  - the applicant uses the same code and cross-section library as was used in NUREG/CR-7108,
  - the applicant uses the same or similar initial assumptions and code modeling options as was used in NUREG/CR-7108,
  - the applicant can justify that their design is similar to the cask system used as the basis for the NUREG/CR-7108 depletion validation, and
  - credit is limited to the specific nuclides listed in ISG-8, Rev. 3.

$^{234}\text{U}$	$^{235}\text{U}$	$^{236}\text{U}$	$^{238}\text{U}$	$^{237}\text{Np}$	$^{238}\text{Pu}$
$^{239}\text{Pu}$	$^{240}\text{Pu}$	$^{241}\text{Pu}$	$^{242}\text{Pu}$	$^{241}\text{Am}$	$^{243}\text{Am}$
$^{95}\text{Mo}$	$^{99}\text{Tc}$	$^{101}\text{Ru}$	$^{103}\text{Rh}$	$^{109}\text{Ag}$	$^{133}\text{Cs}$
$^{143}\text{Nd}$	$^{145}\text{Nd}$	$^{147}\text{Sm}$	$^{149}\text{Sm}$	$^{150}\text{Sm}$	$^{151}\text{Sm}$
$^{152}\text{Sm}$	$^{151}\text{Eu}$	$^{153}\text{Eu}$	$^{155}\text{Gd}$	–	–

# Criticality Validation Technical Approach

- **Challenge:**

- Existing/available laboratory critical experiments (LCEs) do not have minor actinides & fission products (FPs) in proportions similar to actual SNF, and hence are not directly usable for validation

# Criticality Validation Technical Approach

- **B&BU based on comparison of calculated  $k_{\text{eff}}$  values and measured data from LCEs to the extent possible**
  - Validation of principal actinides – utilize available LCE data
- **Validation of FPs and minor actinides**
  - Utilize available LCE data to estimate bias
  - Use nuclear data uncertainties and calculated application sensitivities to estimate potential biases for all relevant nuclides
  - Verify estimated biases through comparisons with calculated biases for cases where LCE data are available, including for the limited available FP LCE data

# Estimating Bias Based on Nuclear Data Uncertainties

- Uncertainty in the system  $k_{\text{eff}}$  is propagated from the cross section uncertainty using the sensitivity coefficient:

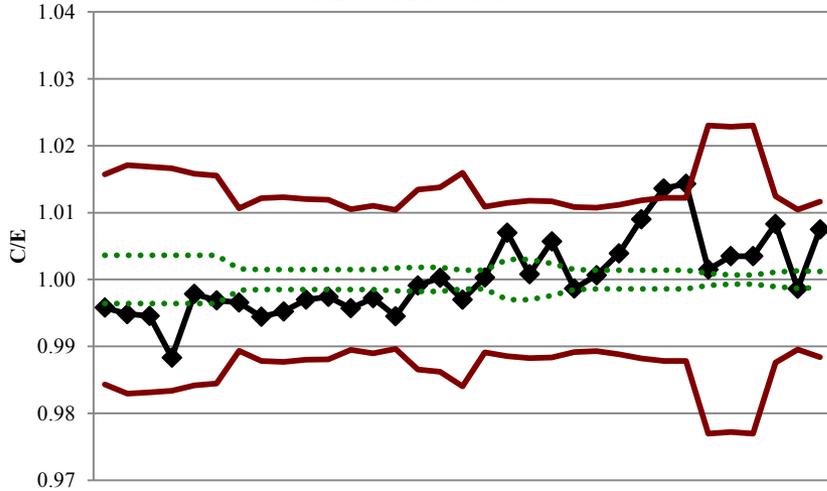
$$\sigma_{k_{\text{eff}}} \left( \frac{\% \Delta k}{k} \right) = \sigma_{\sigma} \left( \frac{\Delta \sigma}{\sigma} \right) \times S \left( \frac{\Delta k / k}{\Delta \sigma / \sigma} \right) * 100\%$$

- Fundamental basis for this approach is that biases caused by nuclear data errors are bounded by the nuclear data uncertainties
- Uncertainty therefore gives an upper bound for the magnitude of the bias

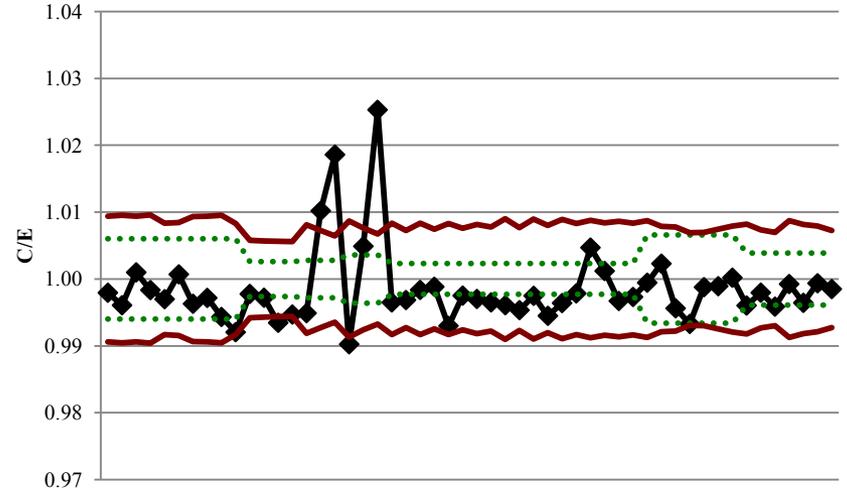
# Examples confirming that computational bias is generally bounded by cross-section uncertainty

◆ Computational Bias  
⋯ Experimental Uncertainty  
— Cross-section Uncertainty

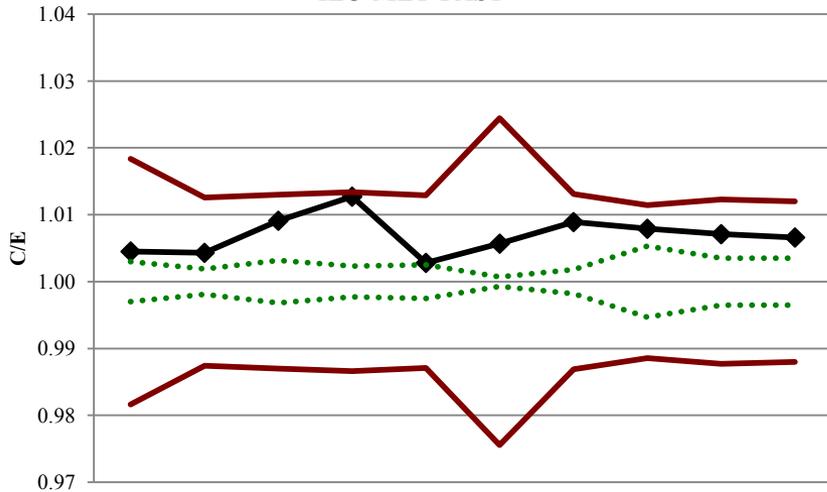
HEU-MET-FAST



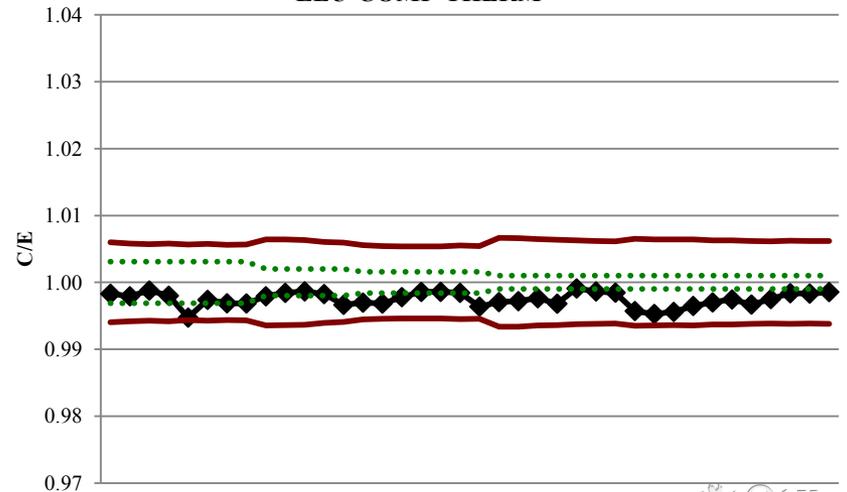
HEU-SOL-THERM



IEU-MET-FAST



LEU-COMP-THERM



# Example Results

Spent fuel pool and GBC-32 cask, fuel burned to 40 GWd/MTU

Uncertainty in  $k_{\text{eff}}$  due to uncertainty in nuclear data

<u>Uncertainty Source</u>	Uncertainty (% $\Delta k/k$ )	
	<u>GBC-32</u>	<u>SFP</u>
All nuclides	0.512	0.491
Actinides-only	0.496	0.480
Structural Materials	0.111	0.073
Primary 6 FP	0.049	0.047
Next 10 FP	0.024	0.023
All Other FP & Actinides	0.037	0.044

# Results

- **Uncertainty due to nuclear data uncertainties investigated for SNF configurations as a function of burnup and a variety of other relevant parameters**
- **Uncertainty determined to be  $< 1.5\%$  of the reactivity worth of the minor actinides and FPs in all cases considered**

# Recommendations (1/2)

- **Validate principal actinides with available LCE data**
  - $^{234}\text{U}$ ,  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{238}\text{Pu}$ ,  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{241}\text{Pu}$ ,  $^{242}\text{Pu}$ ,  $^{241}\text{Am}$
  - HTC experiments and several in the International Handbook are useful for burned fuel

# Recommendations (2/2)

- **A conservative estimate for the combined bias and bias uncertainty associated with minor actinide and FP nuclides of 1.5% of their worth may be used. This estimate is appropriate provided the applicant:**
  - **uses the SCALE code system with the ENDF/B-V, ENDF/B-VI, or ENDF/B-VII cross section libraries,**
  - **uses the same or similar initial assumptions and code modeling options as were used in NUREG/CR-7109,**
  - **can justify that their design is similar to the cask system used as the basis for the NUREG/CR-7109 criticality validation, and**
  - **demonstrates that the combined minor actinide and fission product worth is no greater than 0.1 in  $k_{eff}$**

# Closure

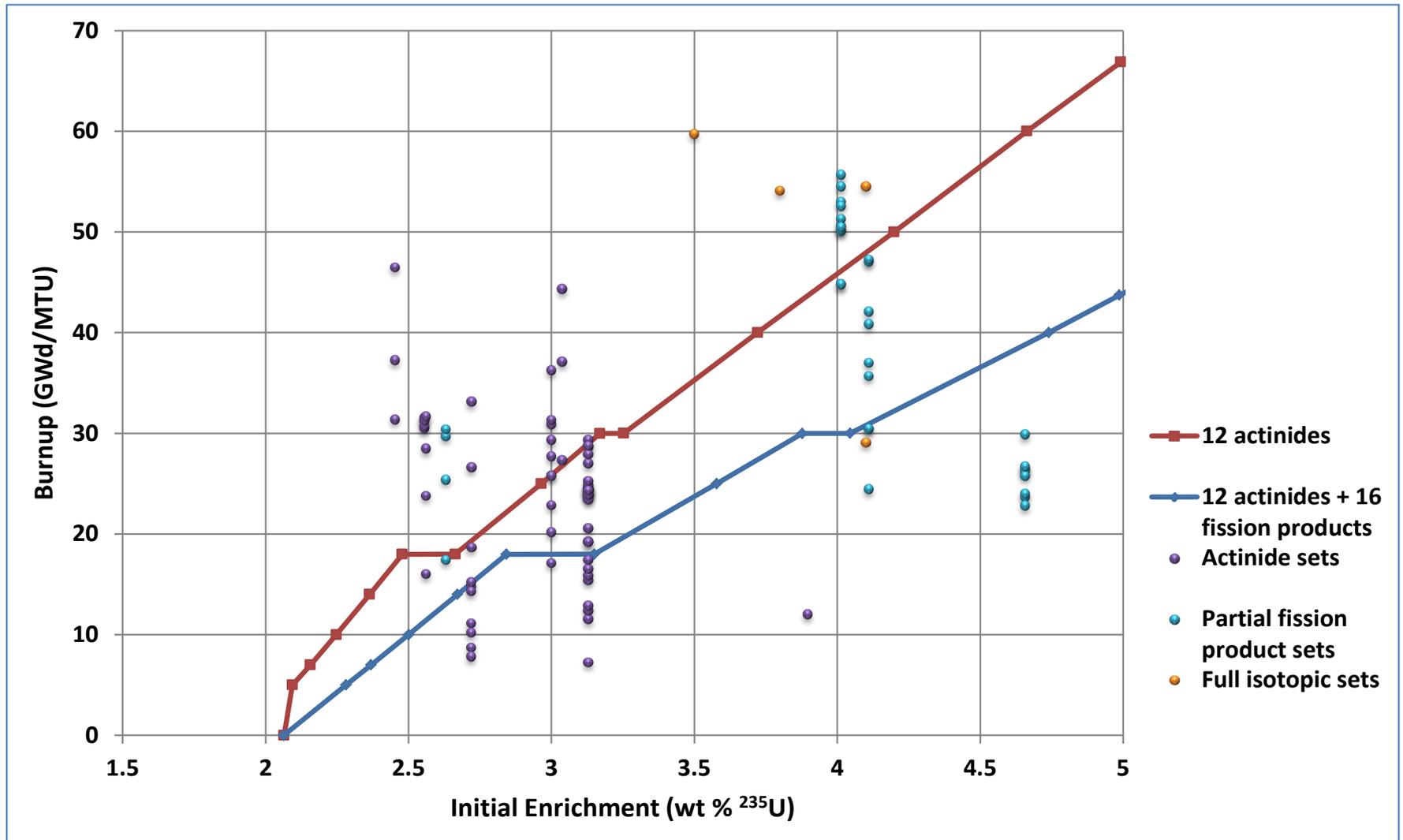
- **Questions / Discussion**
  
- **Acknowledgment**
  - **This work was supported by the U.S. Nuclear Regulatory Commission (RES, NMSS, NRR, and NRO)**

# Nuclides Important to Burnup Credit

$^{234}\text{U}$	$^{235}\text{U}$	$^{236}\text{U}$	$^{238}\text{U}$	$^{237}\text{Np}$	$^{238}\text{Pu}$
$^{239}\text{Pu}$	$^{240}\text{Pu}$	$^{241}\text{Pu}$	$^{242}\text{Pu}$	$^{241}\text{Am}$	$^{243}\text{Am}$
$^{95}\text{Mo}$	$^{99}\text{Tc}$	$^{101}\text{Ru}$	$^{103}\text{Rh}$	$^{109}\text{Ag}$	$^{133}\text{Cs}$
$^{143}\text{Nd}$	$^{145}\text{Nd}$	$^{147}\text{Sm}$	$^{149}\text{Sm}$	$^{150}\text{Sm}$	$^{151}\text{Sm}$
$^{152}\text{Sm}$	$^{151}\text{Eu}$	$^{153}\text{Eu}$	$^{155}\text{Gd}$	-	-

- Credited nuclides based on their importance to SNF reactivity and on availability of RCA data
- Nuclides important to SNF reactivity previously evaluated in NUREG/CR-6665 & ORNL/TM-12973
- 12 major and minor actinide nuclides (all very long lived except for  $^{241}\text{Pu}$  [ $T_{1/2}=14.4$  y];  $^{238}\text{Pu}$  [ $T_{1/2}=87.7$  y]; and  $^{241}\text{Am}$  [ $T_{1/2}=432.7$  y])
- 16 fission product (FP) nuclides (all stable or very long lived except for  $^{151}\text{Sm}$  [ $T_{1/2}=90$  y])

# PWR RCA Data for Burnup Credit Nuclides



# MC Uncertainty Sampling Method Steps

- **Sample from the distribution models established for the bias associated with predicted isotopic concentrations**
- **Adjust the predicted isotopic concentrations using the sampled random values**
- **Use the adjusted isotopic concentrations in the criticality model and calculate  $k_{\text{eff}}$**
- **Repeat the procedure for a statistically significant number of criticality calculations**
- **Determine the mean and standard deviation of the  $k_{\text{eff}}$  values**
- **Establish the B&BU in  $k_{\text{eff}}$  based on the upper limit of the one-sided tolerance interval for 95% of the population and 95% confidence**

# Validation Results for the GBC-32 Cask Model

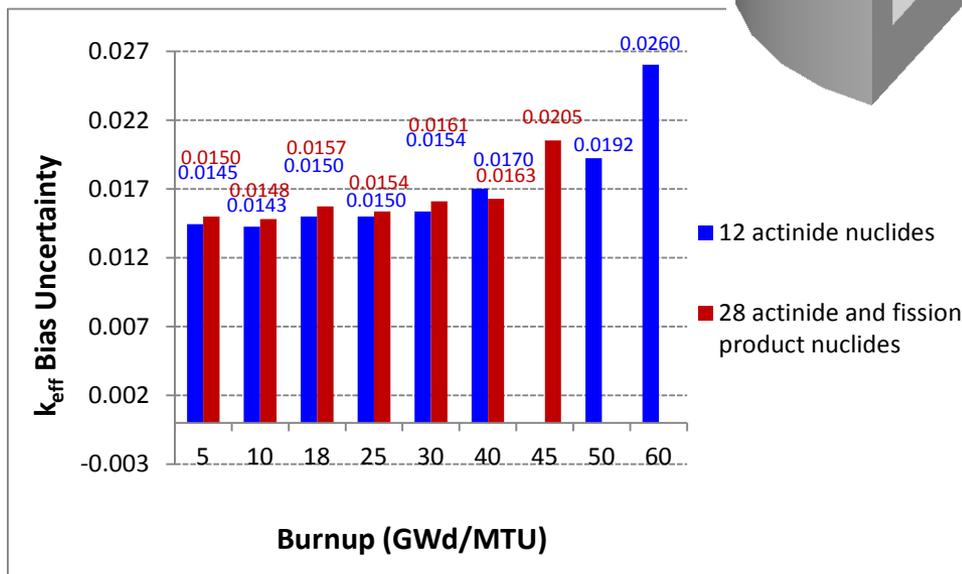
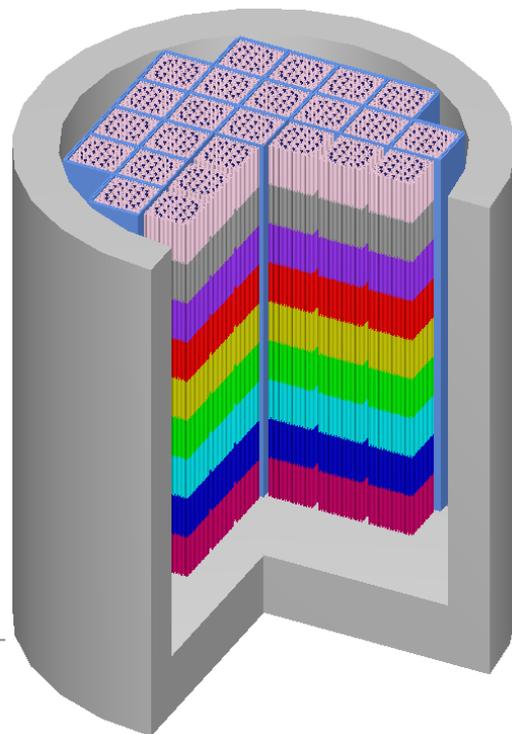
Burnup <sup>a</sup> (GWd/MTU)	Actinides only		Actinides and fission products	
	$k_{eff}$ bias <sup>c</sup>	$k_{eff}$ bias uncertainty <sup>d</sup>	$k_{eff}$ bias <sup>c</sup>	$k_{eff}$ bias uncertainty <sup>d</sup>
5	0.0042	0.0145	0.0040	0.0150
10	0.0040	0.0143	0.0039	0.0148
18	0.0036	0.0150	0.0037	0.0157
25	0.0047	0.0150	0.0023	0.0154
30	0.0052	0.0154	0.0031	0.0161
40	0.0059	0.0170	0.0012	0.0163
45 <sup>b</sup>	----	----	0.0050	0.0205
50	0.0073	0.0192	----	----
60	0.0107	0.0260	----	----

<sup>a</sup>Fuel initial enrichment values are such that the  $k_{eff}$  value based on the predicted nuclide compositions is 0.94.

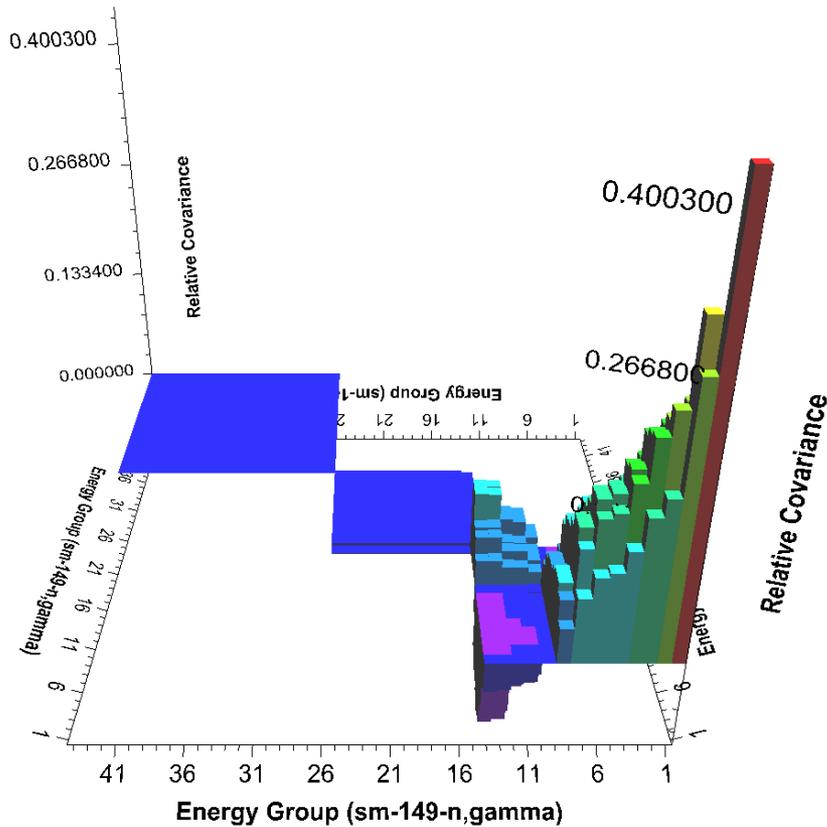
<sup>b</sup>Initial enrichment is 5 wt% <sup>235</sup>U.

<sup>c</sup>Positive bias is typically not credited in criticality safety analyses.

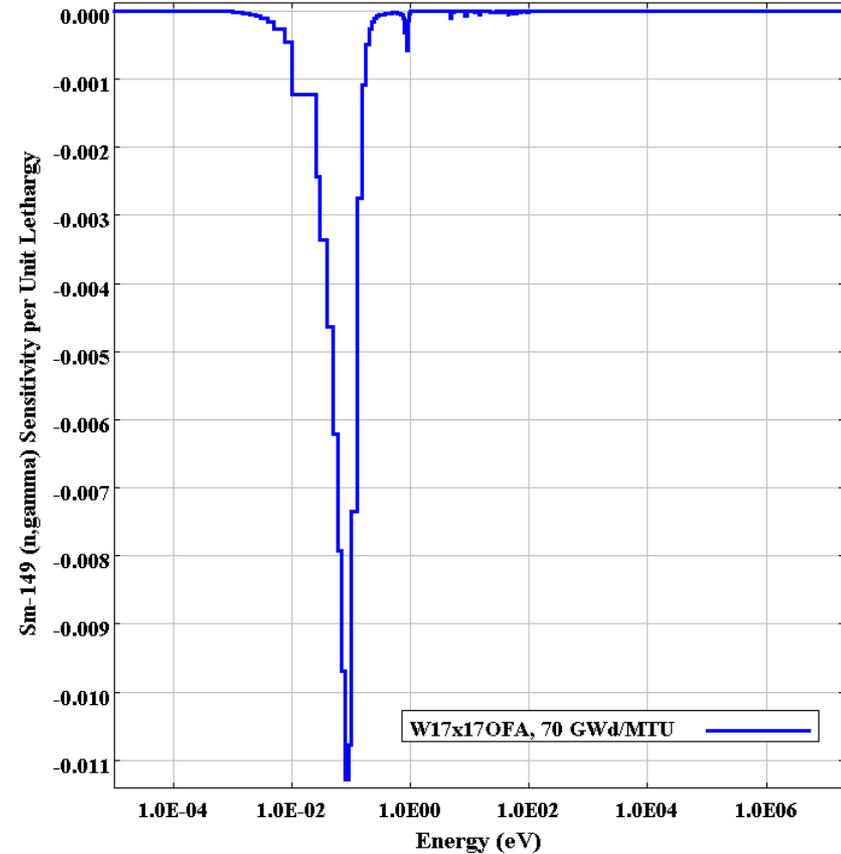
<sup>d</sup>Based on the 95%/95% tolerance interval.



# Uncertainty Analysis



Covariance Data  $[(\Delta\sigma/\sigma)^2]$



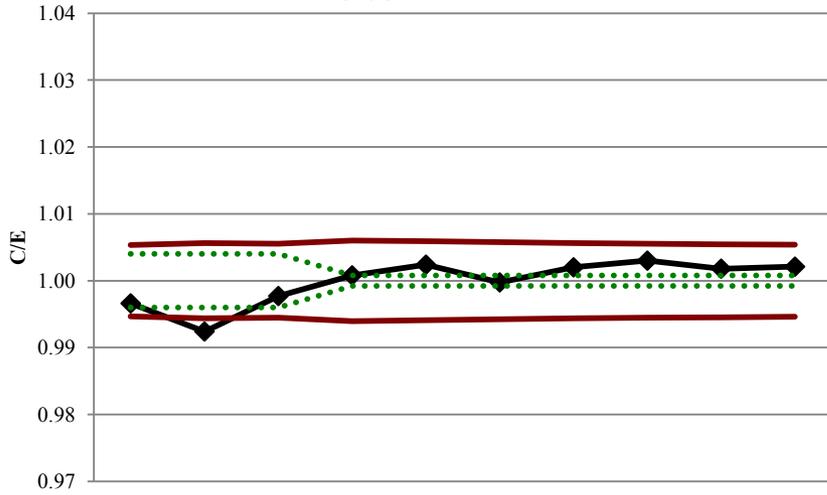
Sensitivity Data  $\{(\Delta k/k) / (\Delta\sigma/\sigma)\}$

combined using appropriate matrix algebra to yield uncertainty in  $k_{\text{eff}}$  due to nuclear data uncertainties

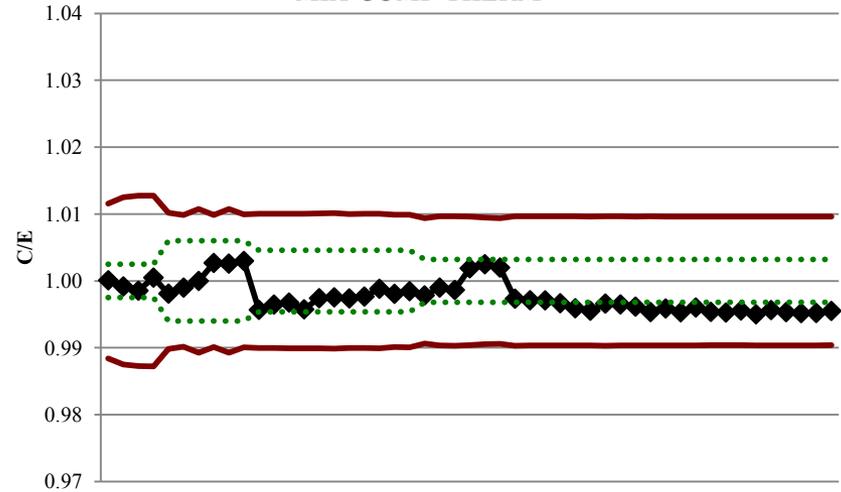
# Examples confirming that computational bias is generally bounded by cross-section uncertainty

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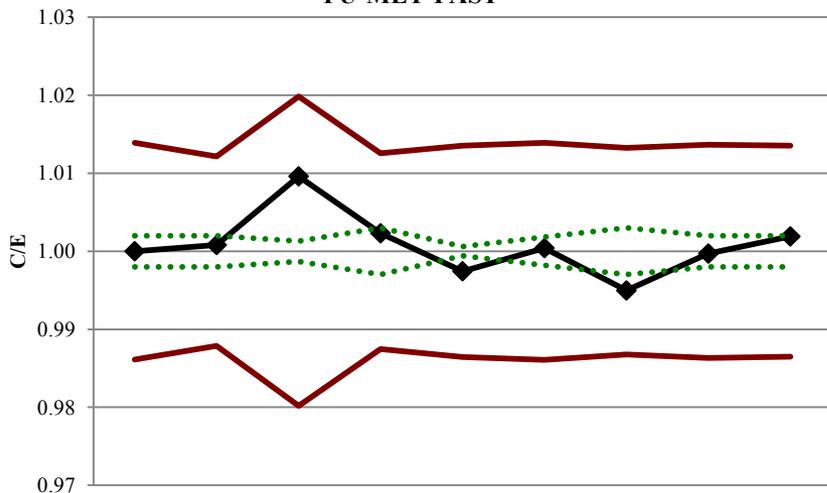
LEU-SOL-THERM



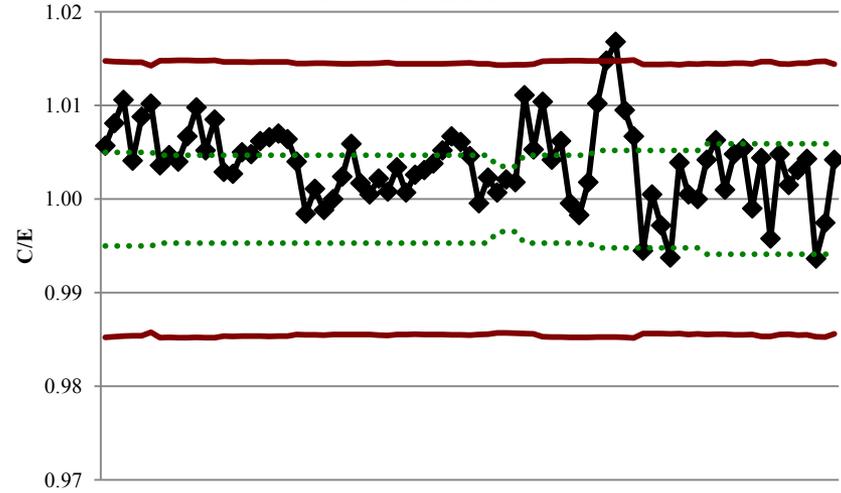
MIX-COMP-THERM



PU-MET-FAST



PU-SOL-THERM





**[Break]**

## Public Comments on Draft ISG-8

- Received comments from:
  - Nuclear Energy Institute
  - Holtec International
  - Nuclear Consultants.com
- Major comments and proposed resolutions

## Turn ISG into a Reg Guide

- ISG consolidates review guidance in one place (as opposed to SRP referencing RG)
- ISG format allows more flexibility to modify guidance to reflect new methodologies (EPRI, BWR burnup credit)
- ISG and Appendix text incorporated directly into criticality chapters of SRPs
- May consolidate guidance into RG at a later date

# Flexibility for alternative validation methodologies

- Validation methodology recommended by ISG-8 represents one method that has been reviewed in detail by the staff and found to be acceptable
- ISG does not exclude alternative methodologies
- Will revise ISG text to state that alternative methodologies should be considered on a case-by-case basis

## Remove burnup measurement

- Measurement recommendation maintained in ISG as an alternative to misload analysis/admin procedures
  - Allows flexibility to applicants if the misload analysis criteria is too restrictive for their specific design
  - Future measurement techniques may make measurement option more appealing

## Administrative loading procedures

- Industry proposed procedures should already be incorporated into cask and site loading procedures; not specific to burnup credit; e.g.:
  - Verify the identity of the fuel assembly prior to loading it into the cask
  - Verify the identity of the fuel assemblies loaded into the cask prior to closing the cask
  - Verify the burn-up values of each fuel assembly to be loaded into the cask from a source QA record prior to loading the first assembly

# Administrative loading procedures (cont'd)

- ISG procedures are intended to be *additional* procedures for burnup credit cask loading, targeted at reducing likelihood or consequences of high-reactivity misload, e.g.:
  - Assurance that there is no fresh fuel in the pool during system loading
  - Verification of the location of high reactivity fuel (i.e., severely underburned fuel) in the spent fuel pool both prior to and after loading
  - Independent, third-party verification of the loading process
- *Recommended* procedures; list not intended to be all-inclusive

# Individual administrative procedures

- Fresh fuel procedures redundant – assure no fresh fuel in the pool or qualitative verification of burnup
- Pool audit within one year of loading burdensome and duplicates some 10 CFR 74 MC&A requirements – Verification of high reactivity assemblies in pool prior to and after loading should be sufficient
- Revise pool audit for loading to QA audit of already loaded canisters prior to shipment
- Clarify intent of other recommended procedures

# Misload analysis recommendations

- $0.02 \Delta k_m$  standard for misload analyses
- Single fresh fuel assembly is acceptable, however:
  - procedures should prevent fresh fuel misloads
  - ISG recommends “reasonably bounding” single misload (95/95 level)
- Multiple assemblies 25% underburned is more simple, however:
  - Depends on loading curve (could be less restrictive than proposed in ISG)
  - ISG recommendation (bounds 90% of total inventory) allows this analysis to be omitted if the loading curve already encompasses 90% of fuel

## Other Comments

- Credit for additional isotopes:
  - Will modify to state that additional isotopes may be credited, provided the bias and bias uncertainty is quantified
- BWR burnup credit:
  - Upcoming RES user need for BWR burnup credit
  - Will revise ISG to state that BWR burnup credit analyses to be reviewed on case-by-case basis
- Applicability to non-intact fuel
  - Will revise this section to include undamaged and damaged fuel (per ISG-1), provided fuel reconfiguration and any additional uncertainties are considered

## Other Comments (cont'd)

- Separate bias and bias uncertainty terms:
  - $\beta_i$  = bias in  $k_{\text{eff}}$  due to depletion code; added to calculated  $k_{\text{eff}}$
  - $\Delta k_i$  = uncertainty in  $\beta_i$ ; statistically combined with other calculation uncertainties
  - $\Delta k_x$  = uncertainty in  $k_{\text{eff}}$  due to uncertainty in minor actinide and fission product cross-section data; treated as bias added to calculated  $k_{\text{eff}}$
- $k_{\text{eff}}$  bias for other criticality codes:
  - $\Delta k_x$  = 1.5% of minor actinide and fission product worth for SCALE code system with ENDF/B-V, -VI, or -VII data
  - Can use same number for other qualified codes with same data, provided minor actinide and fission product worth is comparable to that calculated with SCALE

## Conclusions and Next Steps

- ISG-8, Revision 3 extends the technical basis for burnup credit to fission products and minor actinides
- Provides alternative to confirmatory burnup measurement
- Generally well-received by industry, with some comments
- Will resolve comments as discussed, revise the ISG, and present to full ACRS in September

# Administrative loading procedures

## ISG:

- Assurance that there is no fresh fuel in the pool during system loading,
- Verification of the location of high reactivity fuel (i.e., severely underburned fuel) in the spent fuel pool both prior to and after loading,
- Qualitative verification that the assembly to be loaded is burned (visual or gross measurement),
- Confirmation that an audit of the pool inventory has been performed no more than one year prior to the time of loading,
- Quantitative measurement of any fuel assemblies without visible identification numbers,
- Independent, third-party verification of the loading process, and
- Minimum required soluble boron concentration in pool water during loading and unloading.

## Industry:

- Verify the identity of the fuel assembly prior to loading it into the cask
- Verify the identity of the fuel assemblies loaded into the cask prior to closing the cask
- Verify the burn-up values of each fuel assembly to be loaded into the cask from a source QA record prior to loading the first assembly
- Reduce the verified reactor record burn-up value by uncertainty in the record value, this is the burn-up value to be used for loading acceptance
- Verify that each fuel assembly to be loaded into the cask satisfies the loading requirements prior to loading the first assembly
- Develop and perform procedures/processes in accordance with the QA program
- Verify that the soluble boron concentration in the pool and cask is greater than the minimum required prior to cask loading



# [EPRI Presentation from Albert Machiels]



# NEI Presentation from Marcus Nichol]



# [Committee Discussion]



# **EPRI Work Relevant to Burnup Credit**

**Albert Machiels**  
Senior Technical Executive

**ACRS Subcommittee on Radiation Protection and Nuclear Materials**  
July 10, 2012 Meeting

# Contents

- *Introduction*
- *Transportation of Spent High Burnup Fuel*
- *Probability of Criticality Event During Transportation*
- *Burnup Credit Validation*
- *Summary*
- *References*

# Introduction – Criticality Safety and Burnup Credit

- Criticality Safety
  - Standards & methodologies were originally developed for the front end of the fuel cycle with pure materials
  - Spent fuel is a challenge
    - ORIGEN follows >2000 nuclides
- “Fresh fuel assumption”
  - Significant conservatism
  - Low-capacity storage and transport systems (more systems, more operations, increased \$)
    - May result in less overall safety (radiological  $\leftrightarrow$  non-radiological)
- Burnup credit (BUC): Getting credit for the reduced reactivity of spent fuel compared to fresh fuel
  - “Actinide-only”, “Actinide + subset of fission products”, “Full BUC”

# Transportation of Spent High Burnup Fuel

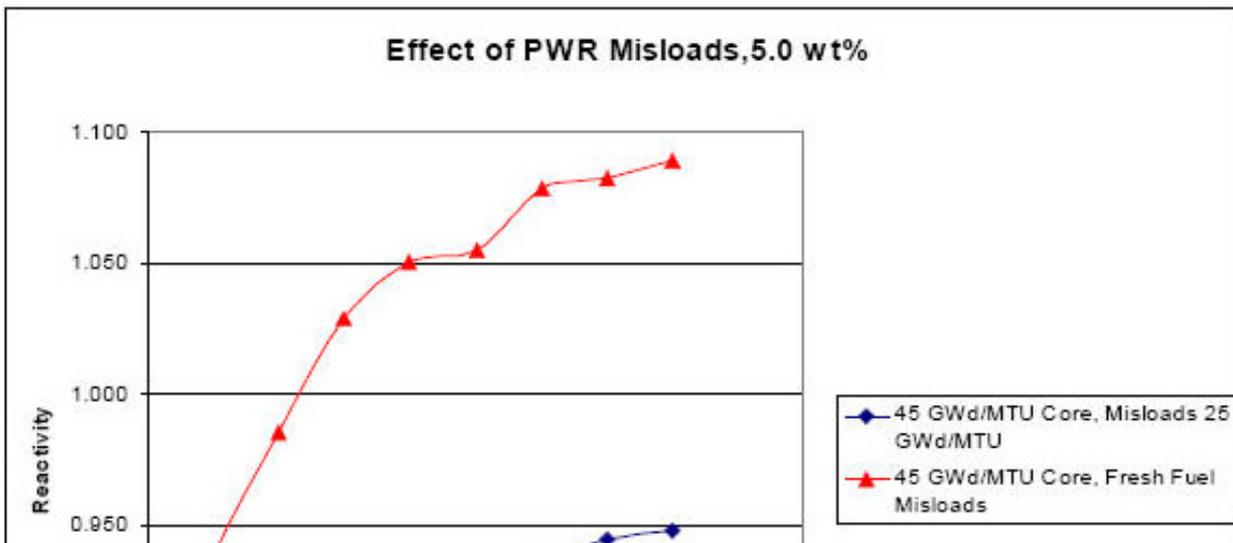
- Key regulatory issue: maintaining sub-criticality under *accident* conditions
- NRC positions:
  - Burnup <45 GWD/MTU: normal assembly configuration
  - Burnup >45 GWD/MTU: fuel reconfiguration cannot be ruled out → “moderator exclusion” or “analytical simulation” option
- Observations
  - High-burnup fuel burned to “design burnup” has low residual nuclear reactivity
  - Should significant reactivity remains (“under-burned”), normal configuration could be assumed
  - With burnup, as cladding properties ↘, nuclear reactivity ↘

# Impact of Spent PWR Fuel Assembly Reconfiguration

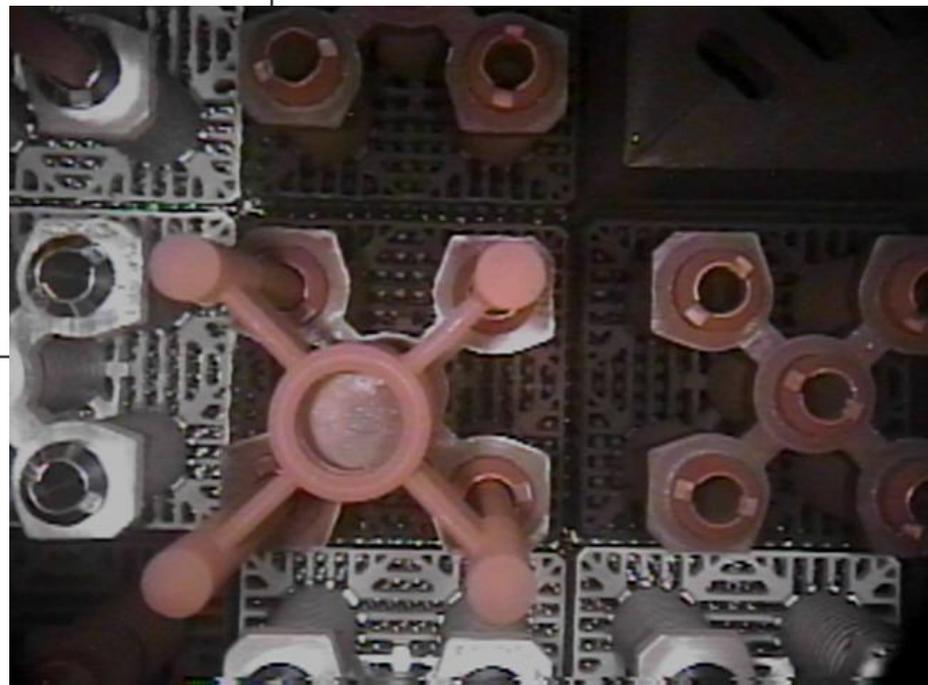
- NUREG/CR-6835 (2003)
  - “Although the scenarios considered go beyond credible conditions, they represent a theoretical limit on the effects of severe accident conditions” (Ref.: page 1)
  - Modest increases ( $<0.05$ ) in  $k_{\text{eff}}$  in “GBC-32” (Ref.: middle column of Table 6)
- EPRI 1015050 (2007)
  - **$k_{\text{eff}}$  is much more likely to decrease than increase**
    - Changes from normal PWR assembly configuration tend to decrease nuclear reactivity

# Impact of Misloads

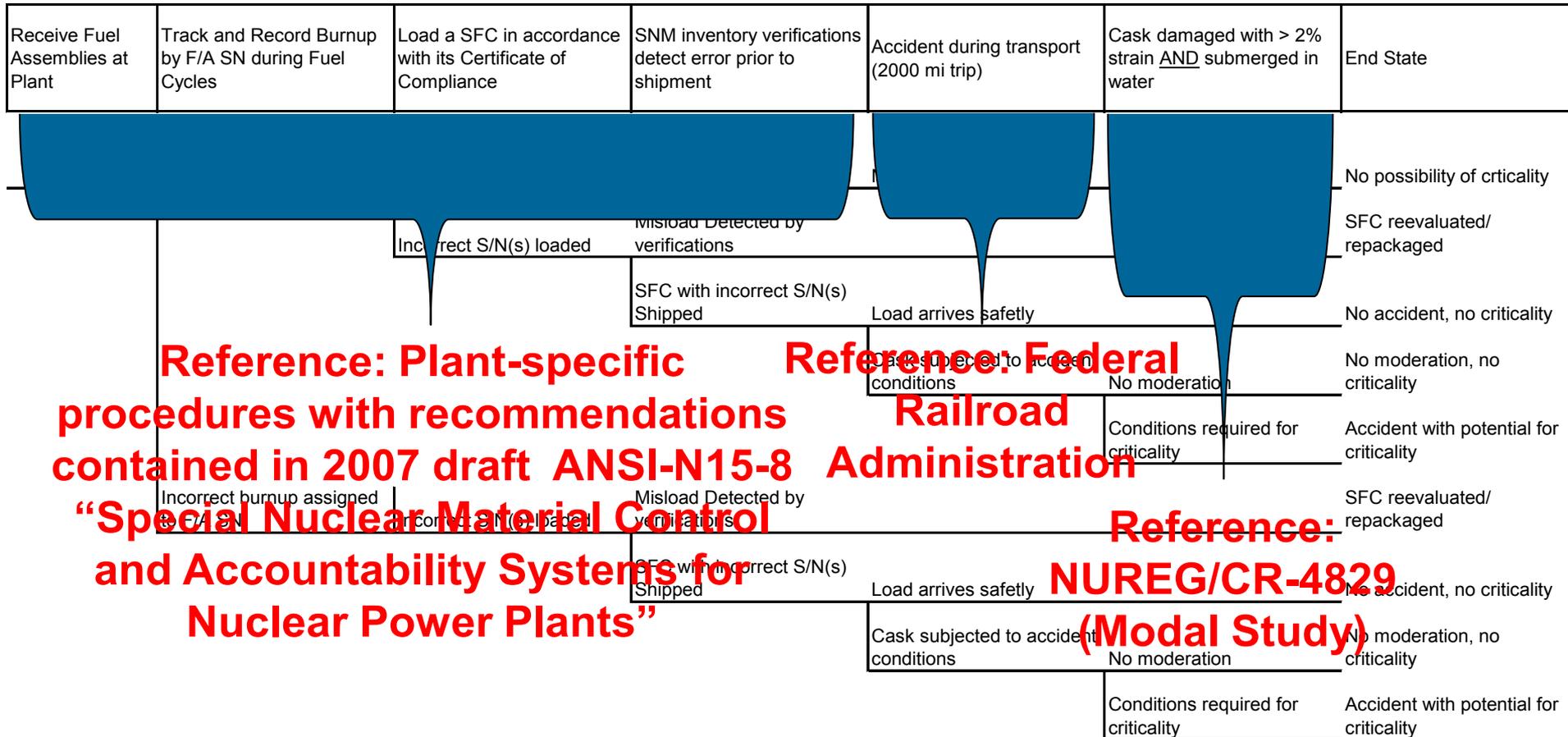
## EPRI Report 1003418 (December 2003)



- **Misloading of fresh fuel is not credible**
- Multiple misloading of significantly underburned fuel is required to introduce enough nuclear reactivity



# Probability of Critical Event During Transportation EPRI Report 1016635 (December 2008)



**Reference: Plant-specific procedures with recommendations contained in 2007 draft ANSI-N15-8 "Special Nuclear Material Control and Accountability Systems for Nuclear Power Plants"**

**Reference: Federal Railroad Administration**

**Reference: NUREG/CR-4829 (Modal Study)**

**Likelihood of a potential criticality event during a 2000-mile railroad shipment of a cask designed for 32 PWR assemblies:  $\sim 1 \times 10^{-16}$ /shipment**

# Burnup Credit Validation

- Main thrust: conservatively estimate loss of nuclear reactivity as a function of burnup (range: 0 to 60 GWD/MTU)
  - Including uncertainty of the estimate
- Alternate approach
  - Based on in-reactor measurements (flux maps)
    - Required as part of routine monitoring of power plant operations
  - Cooperative effort involving Duke-Energy, Studsvik Scandpower, and Dr. Dale Lancaster
    - Principal Investigator: Prof. Kord Smith (MIT)

# Flux Maps: Individual Assembly Reaction Rates

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							0.499 0.491 0.008			0.483 0.483 0.000					
2		0.369 0.389 -0.020				0.998 1.008 -0.006		0.996 0.991 -0.004							
3							1.195 1.175 0.020			1.081 1.069 0.012		0.998 0.985 0.012		0.370 0.382 -0.012	
4		0.610 0.627 -0.017	0.997 0.994 0.003				1.315 1.323 -0.008								
5					1.309 1.298 0.010				1.330 1.331 -0.001		1.309 1.304 0.005		1.177 1.170 0.007		
6	0.484 0.479 0.004		1.082 1.071 0.011			1.331 1.332 -0.001									
7				1.191 1.179 0.011			1.276 1.287 -0.011			1.236 1.224 0.011			1.270 1.274 -0.004		
8	0.475 0.478 -0.003		1.196 1.183 0.013		1.232 1.224 0.008		1.209 1.206 0.003					1.317 1.319 -0.002	1.195 1.178 0.017	0.996 0.995 0.001	
9		0.958 0.951 0.007							1.278 1.272 0.006		1.332 1.317 0.014				0.497 0.501 -0.004
10												1.296 1.298 -0.002			
11	0.355 0.372 -0.018				1.306 1.323 -0.017			1.233 1.212 0.020			1.308 1.305 0.004				0.354 0.370 -0.015
12						1.294 1.305 -0.011			1.192 1.182 0.009			1.170 1.173 -0.003			
13			0.876 0.876 0.000		1.170 1.188 -0.018			1.196 1.183 0.013						0.369 0.383 -0.014	
14		0.369 0.395 -0.026					0.956 0.938 0.018			1.000 0.996 0.003		0.611 0.642 -0.032			
15					0.354 0.366 -0.012			0.475 0.476 -0.001							

- Miniature fission chambers are inserted in the central instrument tubes of selected assemblies

- This is a high precision measurement of the core-wide distribution of fission rates (<1% statistical error)

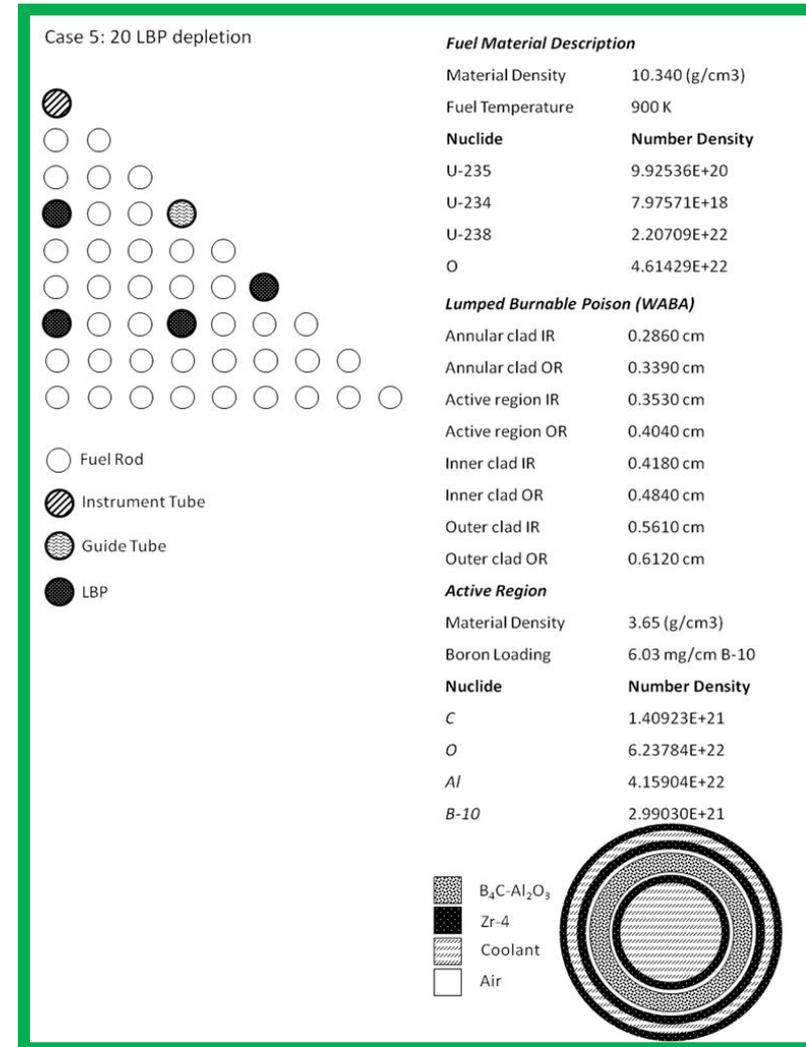
- BOC calculations required by NRC to be within a prescribed tolerance of measurement - to assure core loading

- Required every 30 days by NRC to guarantee that the core is operating within design margins

Reaction Rate  
SIMULATE-3  
MEASURED  
S3-MEAS

# 11 Reactivity Decrement Benchmarks for 17 x 17 PWR Fuel Designs

Table 13.1 Benchmark Lattice Cases	
1	3.25% Enrichment
2	5.00% Enrichment
3	4.25% Enrichment
4	off nominal pin diameter depletion
5	20 LBP depletion
6	104 IFBA depletion
7	104 IFBA plus 20 LBP depletion
8	high boron depletion=1500 ppm
9	branch to hot rack (150F coolant/fuel)=338.7K
10	branch to high rack boron = 1500 ppm
11	high power depletion*(power, coolant/fuel temp)



Measured Reactivity Decrement						
Case	Burnup (GWd/T)					
	10	20	30	40	50	60
1	-0.1329	-0.2339	-0.3211	-0.3956	-0.4554	-0.5002
2	-0.1146	-0.2021	-0.2806	-0.3545	-0.4238	-0.4867
3	-0.1223	-0.2157	-0.2990	-0.3758	-0.4445	-0.5029
4	-0.1207	-0.2176	-0.3075	-0.3931	-0.4715	-0.5385
5	-0.2045	-0.2335	-0.2998	-0.3717	-0.4372	-0.4932
6	-0.1736	-0.2215	-0.2968	-0.3726	-0.4418	-0.5009
7	-0.2524	-0.2418	-0.2981	-0.3686	-0.4343	-0.4910
8	-0.1216	-0.2129	-0.2932	-0.3662	-0.4310	-0.4860
9	-0.1237	-0.2171	-0.2998	-0.3756	-0.4432	-0.5005
10	-0.0967	-0.1784	-0.2530	-0.3217	-0.3826	-0.4335
11	-0.1235	-0.2149	-0.2945	-0.3664	-0.4299	-0.4838

# Comparison between “Draft ISG-8, Rev 3” and “Depletion Benchmarks”

Bias Plus Uncertainty in k		
Burnup	Draft ISG-8, Rev 3	Depletion Benchmarks
10	0.015	0.008
20	0.016	0.008
30	0.016	0.008
40	0.022	0.008
50	0.030	0.008
60	0.030	0.008

- Both results are for SCALE and ENDF/B-VII
- **“Depletion Benchmarks” uncertainty includes all nuclides** rather than the more limited number of nuclides allowed by Draft ISG-8, Rev 3
- “Depletion Benchmarks’ value is dominated by measurement uncertainties, therefore not burnup dependent. Draft ISG-8, Rev 3 values dominated by chemical assay uncertainties

# Summary

- Alternative Approach Relying on Full Burnup Credit
  - Experimental depletion benchmarks
  - Applicable to storage (wet and dry), transportation, disposal
- Spent High-burnup Fuel Transportation
  - Burnup credit is a high priority topic
    - Increased cask capacity (32 vs. 24 assemblies)
    - Loading a greater percentage of spent fuel population
  - Extremely low probability for the potential of a critical event during transportation of commercial spent high-burnup fuel

*“Removal of extreme conservatism can result in an overall improvement in safety by balancing criticality risks with other operational risks” [C. Parks (ORNL), Closing Review Session of 2011 International Conference on Nuclear Criticality (ICNC2011)]*

# References

- Transportation of High Burnup Fuel
  - *Transportation of Commercial Spent Nuclear Fuel – Regulatory Issues Resolution*, EPRI, Palo Alto, CA: 2010. 1016637.  
<http://mydocs.epri.com/docs/public/0000000000001016637.pdf>
  - Machiels, A. and J. Kessler, *A multi-facet approach for evaluating criticality risks during transportation of commercial spent nuclear fuel*, PATRAM 2010, London, United Kingdom, October 2010

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- Probability of Critical Event During Transportation
  - *Criticality Risks During Transportation of Spent Nuclear Fuel – Revision 1*, EPRI, Palo Alto, CA: 2008. 1016635.  
<http://mydocs.epri.com/docs/public/0000000000001016635.pdf>
  - Dykes, A. and A. Machiels, *Criticality risks during transportation of spent nuclear fuel,*” Packaging, Transport, Storage & Security of Radioactive Material, Volume 21, No. 1, 2010, pp. 51-61.
  - Dykes, A. and A. Machiels, *Assessment of the Likelihood of Shipping a Spent Fuel Cask Susceptible to Criticality*, PSAM11 & ESREL 2012, Helsinki (Finland), June 2012.

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- Misload Analyses

- *Burnup Credit – Technical Basis for Spent-Fuel Burnup Verification*, EPRI, Palo Alto, CA: 2003.

- <http://mydocs.epri.com/docs/public/0000000000001003418.pdf>

- *Criticality Analysis of Assembly Misload in a PWR Burnup Credit Cask*, ORNL, Oak Ridge, TN: 2008. NUREG/CR-6955.

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- Impact of Fuel Reconfiguration
  - *Effects of Fuel Failure on Criticality Safety and Radiation Dose for Spent Fuel Casks*, ORNL, Oak Ridge, TN: 2003. NUREG/CR-6835
  - *Fuel Relocation Effects for Transportation Packages*, EPRI, Palo Alto, CA: 2007. 1015050  
<http://mydocs.epri.com/docs/public/0000000000001015050.pdf>
  - Wells, A. and A. Machiels, *Effects of Fuel Relocation for Transport Casks*, to be published in *Nuclear Technology*, Volume 179 (August 2012)

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- Depletion Benchmarks

- *Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty*, EPRI, Palo Alto, CA: 2011. 1022909.  
<http://mydocs.epri.com/docs/public/0000000000001022909.pdf>
- Smith, K., D. Lancaster, and A. Machiels, *Experimental Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty*, ICNC2011, Edinburgh (Scotland), September 2011.
- Lancaster, D., K. Smith, and A. Machiels, *Utilization of the EPRI Fuel Reactivity Depletion Benchmarks in PWR Spent Fuel Pool Criticality Analysis*, ICNC2011, Edinburgh (Scotland), September 2011.

# References (continued)

- Depletion Benchmarks (continued)
  - *Utilization of the EPRI Depletion Benchmarks for Burnup Credit Validation*, EPRI, Palo Alto, CA: 2012. 1025203.  
<http://mydocs.epri.com/docs/public/0000000000001025203.pdf>
  - Lancaster, D., and A. Machiels, *Utilization of the EPRI Depletion Benchmarks for Burnup Credit Validation*, PHYSOR 2012, Oak Ridge (TN), April 2012.

# Back-up Slides

# Fuel Reconfiguration – Beyond Credible Scenarios NUREG/CR-6835 (September 2003)

**Table 6: Maximum increase in  $k_{eff}$  for each fuel failure scenario\***

Scenario	MPC-24 <i>(fresh fuel)</i>	GBC-32 (45 GWd/MTU)	MPC-68 <i>(fresh fuel)</i>
Single missing rod	0.0019	<0.0010	0.0036
Multiple missing rod	0.0140	0.0130	0.0120
Cladding removed from all fuel rods	0.0468	0.0349	0.0441
Fuel rubble (no cladding)	0.0563	0.0233	0.1149
Assembly slips 20 cm above or below neutron poison panels	0.0021	0.0435	0.0362
Variation in pitch (without cladding)	0.0703	Not calculated	0.1225

\* ***“Although the scenarios considered go beyond credible conditions, they represent a theoretical limit on the effects of severe accident conditions” (NUREG/CR-6835, p. 1)***

# Quantification of Human Failure Events Leading to a Misloaded Dry Spent Fuel Cask

FMS	Refueling Engineer (RE)	FMS Supervisor	Refueling Engineer and Crew	Refueling Engineer and Rep. from Nuclear Oversight	Third Party	Third Party	Scenario Likelihood
Select F/As for DSC in compliance with CoC	Prepare FMSDS from DSC Fuel Loading Pattern Form	Verify FMSDS S/Ns and DSC locations against DSC Fuel Loading Pattern Form	Individually Transfer 32 F/As from SFP to DSC	Verify F/A S/N against DSC Fuel Loading Pattern Form using 3-Way communication	Independent Verification via Review of Video against DSC Fuel Loading Pattern Form	Perform independent SNM inventories and/or audits prior to shipment	
HASEL1	HAFMS1	HRFMS1	HATRN1	HRDSC1	HRDSC2	HRSEL1	
9.998E-01	9.9E-01	NA	9.9E-01	NA	NA	NA	OK
			8.7E-03	9.97E-01	NA	NA	OK
				2.8E-03	9.3E-01	NA	OK
					7.4E-02	9.9E-01	OK
						1.04E-02	1.9E-08
	1.3E-02	9.3E-01	9.9E-01	NA	NA	NA	OK
			8.7E-03	9.97E-01	NA	NA	OK
				2.8E-03	9.3E-01	NA	OK
					7.4E-02	9.9E-01	OK
						1.04E-02	2.3E-10
		6.6E-02		9.97E-01	NA	NA	OK
				2.8E-03	9.3E-01	NA	OK
					7.4E-02	9.9E-01	OK
						1.04E-02	1.8E-09
2.50E-04						9.9E-01	OK
						1.04E-02	2.6E-06

From EPRI Report 1016635

Total likelihood of a spent fuel cask shipment with one or more misloaded F/As = 2.6E-06

# Importance of a Centralized Accounting System

- ANSI 15-8, *Special Nuclear Material Control and Accounting Systems for Nuclear Power Plants*, provides reasonable guidelines to record, track, and verify F/A burnup in a centralized accounting system
- Core follow software provides accurate information of the burnup of fuel assemblies. Each spent F/A can be directly associated with its burnup history over multiple fuel cycles
- At any time before a spent fuel cask is shipped
  - F/A burnup and SNM content can be verified against in-core detector measurements and core follow calculations for reactor controls by F/A serial number.
  - Video of F/A serial numbers during cask loading provides ability to independently verify proper loading

# Train Accident Initiating Events

Case Study Number	Case Study Initiating Event Description	Point Estimate Frequency (Events/Train-Mile)
1	<div style="border: 2px solid red; padding: 5px; display: inline-block; color: red; font-weight: bold;">From EPRI Report 1016635</div>	4.33E-06
2	All Train Accidents per Train-Mile (All Accidents, All Speeds, All Track Classes), 2000 - May 2006.	2.67E-06
3	Freight Train Accidents per Freight Train-Mile (All Accidents, All Speeds, All Track Classes), 2000 - May 2006.	2.25E-06
4	Freight Train Accidents per Freight Train-Mile (Accidents with Primary or Secondary Derailments, All Speeds, All Track Classes), 2000 - May 2006.	2.25E-06
5	Freight Train Accidents per Track Class 3+ Freight Train-Mile (using Table 2-4 of Ref. 8) with Speed $\geq$ 30 MPH, 2000 - May 2006.	6.51E-07
6	Freight Train Accidents per Freight Train-Mile (Accidents with HAZMAT Car Damage, All Speeds, All Track Classes), 2000 - May 2006.	3.06E-07
7	Freight Train Accidents per Freight Train-Mile (Accidents with HAZMAT Car Damage, $\geq$ 30 MPH, Track Class 3+), 2000 - May 2006.	8.45E-08
8	HAZMAT Freight Train Primary and Secondary Derailment Accidents per Track Class 4+ Freight Train-Mile (using Table 2-4 of Ref. 8) with Speed $\geq$ 60 MPH, 2000 - May 2006.	1.05E-08
8	Freight Train Primary and Secondary Derailment Accidents per Freight Train-Mile (Accidents with HAZMAT Car Damage, $\geq$ 60 MPH, Track Class 4+), 2000 - May 2006.	8.01E-09

# **Burn-up Credit for Spent Nuclear Fuel Storage Casks and Transport Packages**

*Industry Perspective*

**Marc Nichol**  
**Nuclear Energy Institute**

**ACRS Sub-Committee Meeting**  
**July 10, 2012**



NUCLEAR  
ENERGY  
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# Industry feedback on ISG-8 Revision 3

- Generally a large improvement from revision 2
- Opportunity for further improvements through flexibility and risk insights
- Five major industry recommendations
  - Burn-up verification
  - Depletion validation – alternative methods
  - Depletion validation – additional isotopes
  - Burn-up credit – applicability to BWR
  - Dual uses of guidance

# Improvements in revision 3

- **Greater benefit to utilizing burn-up credit**
  - Now includes limited set of fission products
  - Range extended from 50 GWd/MTU to 60 GWd/MTU
- **Use of risk insights**
  - Smaller administrative margin for misload analyses
- **Improved flexibility**
  - Alternative to in-pool measurements

# Burn-up verification

- Verification method should most effectively and efficiently address the situations that could lead to a misload
  1. Loading the wrong fuel assembly
  2. Calculating a burn-up value higher than actual
  3. Assigning the wrong burn-up value to a fuel assembly

Element	Draft ISG-8 use	Industry recommended use
Burn-up Measurement	Primary method of verification	Do not use
Misload analyses	Alternative to measurements	Defense-in-depth to Admin procedures
Admin procedures	Defense-in-depth to Misload analyses	Primary method of verification

# In-pool burn-up measurements

- Should be eliminated from guidance
- Do not address
  1. Loading the wrong fuel assembly<sup>1</sup>
  3. Assigning the wrong burn-up value to a fuel assembly
- Less effective than admin procedures for
  2. Calculating a burn-up value higher than actual
- Reactor records are very accurate (within ~2%)
- Reactor records calibrated with in-core measurements
- In-pool measurements use reactor records to calibrate
- In-pool measurements are inaccurate, and problematic to implement

# Administrative procedures

- Most effective means to address potential misloads
- Industry recommends comprehensive set of procedures that adequately address potential types of misload
  1. *Verify identity of fuel prior to loading*
  2. *Verify identity of fuel prior to closing cask*
  3. *Verify burn-up value from source QA record*
  4. *Reduce reactor record by associated uncertainty*
  5. *Verify fuel meets loading criteria*
  6. *Develop/perform procedure/process according to QA program*
  7. *Verify soluble boron greater than minimum prior to loading*

# Administrative procedures (cont'd)

- **Some procedures are not recommended**
  - *Verify location of high reactive fuel in pool* – less effective and more resources than industry recommended procedure
  - *Qualitative (e.g. visual)* – mitigates consequence only
  - *No fresh fuel in pool* – mitigates consequence only, duplicative
  - *Pool inventory audit* – duplicate/supersede other regulations
  - *Independent 3<sup>rd</sup> party* – inconsistent with NRC's QA requirements
  - *Quantitative measurement if no ID* – not anticipated, handle as exceptional case, not as something expected to be routine

# Misload analyses

- **Do not reduce chance of misload, only manages consequences**
- **Should be simple and straightforward for**
  - **CoC holders to analyze**
  - **Licensees to verify**
- **Industry recommended assumptions<sup>1</sup>**
  - **Single misload – most reactive fresh fuel**
  - **Multiple misload – 50% with 25% under-burned**
- **Guidance should allow other approaches, if justified**
  - **E.g. if “no fresh fuel in pool” is elected, then single misload could assume a slightly burned assembly**

# Depletion validation – flexibility

- **Currently endorses ORNL developed methodology<sup>1</sup>**
  - **Overly conservative, due to measurement uncertainties**
  - **Limited isotopes available for credit**
  - **Complex**
  - **Requires significant effort to implement**
- **Guidance could be more efficient if flexibility added**
  - **Method to credit additional isotopes if data available**
  - **Considerations for proposing alternative methods<sup>2</sup>**
- **Potential application of burn-up credit for BWR**



1) Documented in NUREG/CR-7108 and NUREG/CR-7109

2) For example, EPRI reports 1022909 and 1025203 detail an alternative approach for burn-up validation and were submitted to NRC/NRR on June 4, 2012 for review and endorsement.

# Conclusions

- **Revision 3 is a significant improvement over revision 2**
- **Industry recommends improvements to burn-up verification for greater effectiveness and efficiency**
- **Industry recommends improvements to burn-up validation for greater flexibility**