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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

In the Matter of:

335th GENERAL MEETING

MORNING SESSION

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

In the Matter of:

335TH GENERAL MEETING

Thursday,
March 10, 1988

Room 1046
1717 H Street, N.W.
Washington, D.C. 20555

The above-entitled matter came on for hearing, pursuant to notice, at 8:30 a.m.

BEFORE: DR. WILLIAM KERR
Chairman
Professor of Nuclear Engineering
Director, Office of Energy Research
University of Michigan
Ann Arbor, Michigan

ACRS MEMBERS PRESENT:

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Vice Chairman
Associate Vice-President for Research
Professor of Nuclear Engineering
The Pennsylvania State University
University Park, Pennsylvania

MR. JESSE C. EBERSOLE
Retired Head Nuclear Engineer
Division of Engineering Design
Tennessee Valley Authority
Knoxville, Tennessee

DR. CHESTER P. SIESS
Professor Emeritus of Civil Engineering
University of Illinois
Urbana, Illinois

DR. HAROLD W. LEWIS
Professor of Physics
Department of Physics
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Santa Barbara, California

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Tennessee Valley Authority
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Retired Chief Engineer
Electrical Division
Duke Power Company
Charlotte, North Carolina

ACRS COGNIZANT STAFF MEMBER:

Raymond Fraley, Executive Director

P R O C E E D I N G S

DR. REMICK: The meeting will now come to order. This is the first day of the 335th meeting of the Advisory Committee on Reactor Safeguards.

During today's meeting the Committee will hear discussion about the following--human factors research needs, operating events and incidents, Rancho Seco Nuclear Power Plant restart, DOE advanced reactor severe accident program, future activities, and recent ACRS subcommittee activities. Topics for consideration on Friday and Saturday are listed on the schedule posted on the bulletin board outside the meeting room.

The meeting is being conducted in accordance with the provisionprovisions of the Federal Advisory Committee Act, the Government and the Sunshine act. Ray F. Fraley is the designated federal official for the initial portion of the meeting.

A transcript of portions of the meeting is being kept. It is requested that each speaker use one of the microphones, identify himself or herself, and speak with sufficient clarity and volume so that he or she can be readily heard.

We received no written statements or requests to make oral statements from members of the public regarding today's sessions.

I will begin with some items of current interest.

(Items of current interest were discussed off the record.)

DR. REMICK: Those are the items of general interest this morning. We will move then to our first item on the agenda this morning, and that is the human factors research needs, and the person who is handling that is Dave Ward, the person who suggested that we have this information briefing on the National Academy of Sciences study. Dave?

MR. WARD: Let's see. Everyone isn't quite here yet. So here is Hal. Now we can start. Maybe, could we just take a five-minute pause until we get--

DR. REMICK: Five-minute.

(There was a brief pause in the proceedings.)

DR REMICK: I would like to reconvene, and I turn the meeting over to Mr. Ward, on human factors research.

MR. WARD: I just want to remind the Committee of where this has come from because we had a hand in it, getting this effort started a couple of years ago.

You may recall that several years ago, the NRC Research Office had a program in human factors which gradually died out. In Chet's research reports, we complained about it every year for three or four consecutive years. A couple of things eventually happened. One was that the National Academy's panel drawn together to give the NRC some advice on

the general topic of research, the so-called--headed by Bob Frosh, had as one of its recommendations that a program in human factors research be, was important and should be restored.

The second thing that happened was that the, really through initiative on the NRC research staff which we endorsed with a letter, the National Academy and the National Research Council was asked to put together a panel to study the, more specifically the need for research in the area of human factors for the for the NRC and the nuclear power industry, so a couple of years ago a panel was put together. The chairman of the panel was Dr. Neville Moray, who is our speaker today, who was then with the Department of Industrial Engineering and professor of industrial engineering at the University of Toronto. He has since moved to Champagne, Urbana and the University of Illinois, and I think the football team anyway is a little bit better in Illinois than at Toronto, although not much, although alumni can't--it doesn't seem to have much of a record, so I don't think those were his reasons for going to Illinois.

But anyway, the panel labored over the course of eighteen months or somewhat longer I think, and has come out with its report. The report has been published. I think Dr. Moray has given a presentation on the report to the human or to the NRC staff management or at least the research

management. Eric Beck George seems committed to develop the new program in human factors research presumably using this report as guidance for that. Neville has come here today to spend about three hours with us giving us a summary of the report. I think you will find that he will be a very knowledgeable and interesting speaker on the topic and he is prepared I think to interact with you and answer questions as we go along.

He also plans as I understand to give a similar report to the commissioners. I think that is scheduled for, I don't know if it is for April or perhaps May.

We also have here Dr. Harold Van Cott from the National Research Council, who is the staff director of this program, and a major participant in the study.

Let's see. I was--just one other little thing. I was a member of the panel, kind of a minor member. I didn't really make an awful lot of input, but I was interested in what was being done, but I think that probably must disqualify me from doing something. I don't know what. I am not sure, but under out rules I think there is something I can't do. I haven't figured out what it is, but I am just telling you that in advance. Some conflict of interest; I can't figure out what interests there are.

DR. SIESS: Not financial anyway.

DR. LEWIS: There really is no conflict.

DR. REMICK: I think he is just informing us he was a member.

MR. WARD: Yes.

DR. SIESS: You would like an apology!

DR. LEWIS: There is no conflict, just that we can't give any credence to your judgment about the quality of the effort, but that's our problem, not yours.

MR. WARD: Okay. I don't think there is anything else then, and so at this time, I will ask Neville Moray to go ahead with his presentation.

DR. REMICK: I will put in a little commercial that the Human Factors Subcommittee will meet on the 28th of this month to consider the NRC human factors research plan.

DR. SHEWMON: Where?

DR. REMICK: Here.

DR. MORAY: Good morning, ladies and gentlemen, and thank you for giving me the opportunity to come and present the results of our work to you.

I wasn't aware at the time of Dave's strange beliefs about college football, but we will forgive him that. Maybe that was the reason he didn't get to meetings, trying to drum up some sort of support for the teams that he supports!

I would like to begin by thanking the National Research Council staff for their support, particularly Dr. Van Cott who is here this morning, and his predecessor, Stan

Deutsch, who gave us enormous help. Also Beverly Huey who is here this morning is my co-editor who worked heroically to produce the report and spent the last few weeks working on it with a fever, a high temperature and driving in and out of Washington every day in order to work on it, and I think she deserves the highest praise for the final presentation of it.

I would also particularly like to thank the people at the NRC for the support they gave us, tom Ryan and Dan Jones in particular who gave us all the assistance that we asked for at every point.

The panel which was convened--by the way, let me say once that if you want to stop me at any time and ask questions, I would be very happy. I prefer in fact that format rather than for me to run on until the end and for you to ask me questions. Please break in at any moment.

The Committee, as the panel, as is characteristic of the National Research Council, was drawn from a wide variety of disciplines because it was felt that at the beginning that there was a heavy tendency for human factors to be thought of as something in control room design. Particularly following the events at Three Mile Island, we felt that that was inadequate definition and that we had to cover a much wider variety of disciplines.

There is plenty of suggestion that major problems in the management and operation of nuclear plants occur in,

management organizational factors, relationships with the regulators, and that end, and right down to certainly still problems with control room design, and therefore, the people who were, drew into the panel included everything from sociologists and economists up to nuclear engineers and people who had been on the executive of a power company. They worked extremely hard, and I consider it a privilege to have been able to work with that group. I was most impressed.

We were given very short briefings by NRC to begin with, two-day briefing. We were able to take the panel to Three Mile Island, visit the, both the plants to introduce those who had not been in the, had anything to do with nuclear work before, which I think was also very valuable. Of the panel, about eleven out of this group people had in some way or other been connected with work to do with the nuclear industry in the past. Some had been actually working in the industry, as for example Ed Smith. Some had been working in universities or research institutes, both in this country and abroad such as Rasmussen and myself. Some had been consultants, so the majority had experience at some level or other of nuclear industry, and the few who had not as I say were put there for their particular skills and were very quickly I think able to appreciate the major points.

Our charge was to identify study areas where there had been inadequate attention paid and where more work

needed to be done. We were not charged, explicitly not charged to do a critical review of NRC's past work, but to say where we thought future research still remained, and that is the reason for the particular emphasis in the final report.

Implicitly in some things we write in the report there is criticism of the past programs of NRC. That is inevitable, and I don't think any of us feel we have to apologize for that, but our main concern is that if there is to be a viable nuclear industry, there is still research that needs to be done on human factors in order to increase safety and to ensure that both the objective safety of the operations are increased and also that it is seen, that the public's view of the industry is one which accepts that safety as being improved.

MR. EBERSOLE: Let me ask a question. TMI was a case like many others where there had been investigations and known deficiencies which would have led to the precise accident that occurred, and there were many other--

DR. REMICK: A little bit louder.

MR. EBERSOLE: There Davis-Besse was a succession of these things where to a greater or less degree the situation exists to cause the particular thing to happen, yet there is, it is impossible to get a reaction from the technical community at large to fix this until something happens.

Are you going to get into the roots of why this is

so?

DR. MORAY: You will see that some of the recommendations we make for research is into how to improve what has come to be called cultural reliability. That is, to try to get an understanding of how either through regulation or through persuasion, management and organizational forces can exactly tackle that problem. It is clear that there is a resistance to change unless very strong and probably usually either economic reasons or regulatory pressure makes people do it.

We would like to feel that something rather more than that could be done. Yet, certainly we are asking for research in that area. We don't know the answers, although there is a large amount of research in industrial sociology which is relevant to that.

MR. EBERSOLE: Thank you.

DR. MORAY: It is also interesting that I recently received actually from a nuclear inspector in Britain a document on the tolerability of risk for nuclear power stations which they just published which is meant to be a document which came out of the Sizewell B inquiry, and this is a public document to explain to the public at large what their attitudes about risk assessment are. And in that, there is a section where they also come out strongly along the lines that there are major problems in management and organizational

control as a source of of problems. I think--I am interested to find that although it is not written for the same purpose, there is a lot in that document which is exactly along the lines that we have suggested.

MR. EBERSOLE: I see.

DR. MORAY: The Canadians also I think are thinking the same way.

(Slide)

DR. MORAY: One useful place to start from is to look back at the history of the NRC's research program up to, up to the time that the program was effectively cancelled two or three years ago.

There certainly has been an extensive amount of research which they have done. The bibliography in our report is quite extensive. I think it runs to rather 150 entries, and we did manage to look at the NRC's publications, NUREGs and NUREGs CRs. There are somewhere around about a hundred, between hundred and 125 publications which have come out on human factors, and by topic they are broken down approximately as this list shows. The numbers don't add up exactly because clearly some of the papers, some of the research reports can be catalogued under different headings, but it is interesting to see where most of the work has been.

Clearly displays and SPDS has been, had received a lot of interest. That represents the response to TMI in terms

of looking into the design of control rooms and trying to put that right.

Performance qualifications and licensing has received a lot--and of course, the outstanding is human error probability in PRA. Now I will come back to that later on because we do have some fairly strong feelings about research in that area.

Briefly, we think that it is very understandable why so much effort has been put into this, but we don't think that research, further research into estimating the probability of human error for PRA along the lines which has been done so far is worth doing. And I will come back to explain in more detail later on, but I think this is perhaps one of the more contentious things. It is something that was said in an earlier program when the Human Factors Society proposed a research program, and I will leave that now, but I will certainly come back to it later.

(Slide)

DR. MORAY: The panel met, as Dave said, for approximately eighteen months. We received briefings from many organizations. We received written communications from nuclear power plant operators, and within our timeframe, we have tried to do as thorough a job as we can. Now as you will see in the report, we have deliberately excluded certain topics, largely because of time.

We have not looked into human factors of waste management. We have not looked into the human factors of security and say anti-terrorist activities or anything of that kind. We felt that there was, we would not be able to do a thorough job if we extended our work that wide, so we are strictly looking at the operation, management, maintenance of really current power plants. We discussed whether we should consider future developments in the next generation of plants. We decided not to do that for two reasons really. One is that it is extremely difficult to guess where technology is going these days. It is changing so fast, that if we tried to guess what the human factors issues would be ten years down the road on the assumption that a new generation of plants is going to be built, it is highly unlikely that our recommendations would have any degree of reality at all.

MR. EBERSOLE: From your basic charge, the panel charge, and from NUMARC, it would appear you have to operate on the presumptive basis that the operators are handed a plant which is designed properly in the first place.

DR. MORAY: No. As you will see in the report, we say that certainly one sense you can give to the word human error is error in initial design.

MR. EBERSOLE: You have that within your scope?

DR. MORAY: It would have been within our scope. We decided not to, as I say, look at that with an eye to future

design.

MR. EBERSOLE: I am talking about past and existing.

DR. MORAY: Yes. I don't think there would be--it is difficult perhaps to see what kind of research you could now do on the current design efforts because there don't seem to be any. The design process I think is not well understood. I mean the nature of engineering design is not well understood. There is research going on not particularly in the nuclear area about, a lot of research going on here and there on designs such as to support engineering teaching in universities, and I think it is worth looking at that.

One of the points we are going to make is that you can really look at research in different ways. There is highly specific research which is directed at particular problems for the nuclear industry, and it is obvious that kind of research should be done.

There is also research on generic topics, fundamental research which is not being directed immediately to the nuclear industry, will relate to problems which are of importance to the nuclear industry simply because they are important to many other industries as well. For example, the causal model of human error which is nothing particularly specific about nuclear, and finally, there is the question of transferring of existing knowledge. The research there is simply a matter of research on how to do it, how to make it

more effective. So yes, we certainly feel that in so far as humans do design and they do construction and they do operation, they do maintenance and they do management and they do decommissions which is another thing we didn't look at specifically, all those areas are areas where if you can reduce the impact of human error, you will by definition improve systems safety.

I think when we, there was one point at which we had an enormous shopping list of research topics. It was considerably, it was considerably longer than the one I just showed you of the work that the NRC has in the past done, and we felt when we were advised at that point and what we discussed at great detail, if we were to be of the greatest assistance to NRC in choosing a research program for the next few years, it was important not simply to list everything that we felt needed research because that runs perhaps to getting on for between 50 and a hundred topics. It was more important to identify a relatively small number of topics which were of greater urgency in the sense that we really felt if they had to choose, these with the ones they should work on over the next three years. In doing that, they would naturally begin to find out other topics and the program should be self-sustaining at least from the point of view of questions. Financing, of course, is another matter.

So what we have given in the report is a relatively

short list of topics, but these are the ones which as I say, we think the NRC should immediately act on.

We have not discussed how much money should be spent. We don't think that's our, that was the panel's problem. That is a problem of management for NRC It is their problem to decide how much money they want to spend on it in the light of their budget in the same way that ultimately they have to decide which of the topics get top priority and also how they are going to manage their overall research.

Now we have talked in the report at considerable length about two topics. One is the nature of human factors, and the other is what we mean by systems approach.

Human factors is clearly still not understood really by engineers although it has become I think better understood in the last few years in the nuclear industry, and I must say I think due to NRC's efforts, perhaps because they have forced the industry to take some notice of it through things like the detailed control room design review.

I am impressed by the extent to which the industry has responded. There was an ANS topical meeting about eighteen months ago, and I was quite interested. I went to that meeting, and I was puzzled why I found the papers rather boring, and toward the end of the meeting, I realized that the reason they were boring was that nobody was arguing about

anything and that what I was listening to were engineers now talking about a certain aspect of human factors such as task analysis as if they took for granted these were good things to do which was a marked change from say three or four years prior to that at Myrtle Beach 1 and 2. I think the message has been getting across. Whether it has been getting across to management is another matter, because ultimately it is a question of investment.

Now regulators can force an industry to respond to safety issues whether the industry likes it or not. We feel and we have said at one point in the report that in fact, by and large, a safe industry is probably a productive industry. Insofar as you can keep the plant up and running, it is actually going to be profitable to be safe. You can reduce human error. You will reduce the number of shutdowns, reduce the number of shutdowns. You reduce stress to the plant, and obviously you keep generating electricity for efficiency, so the industry actually in many occasions I think it should be possible to persuade the industry and management that actually it is not merely cost that goes into the kind of things that we are suggesting, but it actually will improve their profitability. That is always difficult to show in a detailed way.

There are cases where specific, specific cases where you can point at very large savings as a result of fairly

large investments in human factors.

So we have gone to some trouble in the report to spell out the nature of human factors as we see it, particularly to make the point that we want to extend human factors to include things which usually come under the helping industrial psychology or sociology of organizations and management.

The reason is that we support very strongly the idea of a systems approach. Now the phrase systems approach is, of course, one of the things that everybody believes in and everybody knows it is a good thing, and we all ought to think like that, particularly complicated industries and complicated processes. We want to give it a bit more coherent description, definition than that, and this picture which comes from one of Shikiar's report who is, he was on our panel, points to what we mean.

One can think of any large industry complex, high technology industry, in the form of this sort of onion-shaped diagram. In the middle, you have the technical engineering system. That's the hardware. That's the plant itself, the control room hardware, so forth.

Outside it you have the personnel sub-system and the interface between the two at A is the place where most conventional human factors has been done, namely, the control room/human machine interface design in the control room, and

there is absolutely no doubt that getting that wrong will cause a great deal of trouble.

There is a rather nice phrase that a friend of mine introduced a few years ago called cognitive impedance matching. The idea is that by analogy with electrical impedance matching, if the properties of the thing inside here and the properties of the thing outside here are not properly matched across the interface, then just as incorrect impedance matching will give you a loss of power with electricity, so incorrect matching between the properties of the hardware and the human will give you a loss of transmission of information and control across the interface, that it is important to understand how to design this interface so that the, the flow of information and control is matched to the properties of the human.

That is what everybody understands, and that's where the major thrust has been since Three Mile Island we feel. The problem is that it is relatively easy to redesign control rooms, and consequently it is relatively easy to, for people to feel that that problem has now been solved and human factors can now be abandoned.

We don't know why NRC dropped its human factors research program. We didn't go on a ferreting expedition to try to see what would come out if we put a ferret down the rabbit hole. I don't think that is our business. The simple

fact remains that the best estimates we have are that somewhere between 30 and 80 percent of industrial incidents and accidents are in some sense or other attributable to human error. Even INPO's data suggest it is about 50 percent in the nuclear industry, and if that's the case, it is very striking that people should not continue to do research on it.

One reason possibly is the feeling that we have done it because we have done the control room. We want to point out that outside that there is the personnel sub-system. This includes factors such as social interaction among operators, problems of defining hierarchy of control in the control room, problems of hierarchial relationships between the operators and the maintenance crews, and the organization and management.

As we say at one point in the report, if you had excellent hardware and excellent plant and bad management, then you are going to have workers who do not use the excellent hardware properly. A very small mistake on the part of management can produce a crisis in morale and willingness to work on the part of operators, which will take months or even years to restore.

It is possible that the major reason why operators at Peach Bottom were asleep was they were merely physically tired, and if so, that in itself is a management problem. It is a management fault because if you look through the NRC's

research on the structure of shift work, it is abundantly clear there is a enormous variety and quite irrational variety of shifts, many of which are of a design which are known to be likely to produce bad work, fatigued workers, and high probability of human error. And it is not the person. It is not the operators who choose the shift work. That is a management problem.

There is many ways--

MR. WARD: Neville, I mean is the point there that--I mean you are talking about shifts in terms of the length of shifts and the sequence of rotation and that sort of thing?

DR. MORAY: Yes.

MR. WARD: Is your point there that there is an existing body of knowledge that could be applied and just hasn't been?

DR. MORAY: There is indeed. We will point out that when I come to the research recommendations. The point I am making here is that however good the hardware is in the plant, and however well intentioned and well motivated the operators are and well trained, if the management is incorrectly done, then you will destroy the overall efficiency of the organization.

The options available to operators and maintenance people here are constrained by what management allows them to

to do and what management demands of them. The behavior you see at this level, at this interface, is not entirely a property merely of the humans at this level. It is also a property of the humans at management and organization. Management can make or break a plant in the way that it makes the workers respond to the demands of management, and it is now increasingly realized not just in this industry, but not just in this country, but other countries and other industries, in the military and so forth, that the problems of management here are absolutely crucial. They may be along with maintenance probably, the two most important factors which are not yet well under control in the industry from the point of view of making it safe.

Certainly we need to do much more research at this level.

Finally, management themselves are under pressure from what we are here calling the environmental context, and that includes the regulatory bodies, the PUCs, the public. The way they are seen are there are now cases where you meet people who, operators who have moved into a new part of the country to work at a plant and when their neighbors discover they are working at a nuclear power plant they are effectively socially ostracized. Now that is not a situation where you are likely to be able to recruit the best people and keep them working well.

And I don't have to tell this audience the amount of pressure that, from the public that is on the industry, and the point is that none of these work in isolation. The regulators here determine in a sense, well, they determine very directly what goes into the control room. Only certain options are possible in the way of equipment and modes of operation given certain regulations. Innovation may be hindered by regulation. Innovation may be hindered by management. It is quite clear that the design of many power stations is the way it is because the management was used to building fossil plants for many years and also because of the influence early on of the nuclear Navy on the way that the industry developed.

You have quite different kinds of plants in other countries which have started from different viewpoints. The mode of regulation is quite different in other countries. To take the, perhaps the extremes, on the one hand you have the American system where it is in a sense clear that the idea is to regulate in detail from the top down, whereas you compare that with say the British mode where it is a responsibility of the plants, of the utilities to make their plants safe. They can do it anyway they like but they then have to prove to the regulators that what they have done is satisfactory, which gives them a much greater flexibility in how they do it.

I am not saying that one or other is guaranteed to

be better. I am just saying that they are different, and in so far as they are different, there is a very tight relation between the regulators out here and the actual choice of hardware in here.

Similarly, the kind of people you can get to be operators affects management. The kind of equipment that is available affects the, what management will expect them, expect to happen in the control rooms. That in turn will affect the regulators because people who invent new devices will come to the regulator and say can we use them?

It is simply not possible to solve a problem by changing any one feature in a diagram like this. That as another, one means of systems approach and research must be done we believe in a systems approach and systems setting. If you look through the published research, one is struck by the fact--I am talking about the NRC NUREGs CRs, one is truck by two things. One is there are very few experiments--lot of surveys, lot of models, lot of reviews. There are very few true experiments.

That is not surprising. It is extremely difficult to do experiments on large, complex systems. For one thing, the kind of people who normally do research at universities can't get at them, and one of our recommendations is that there should be an improved, somebody should set up improved channels of communication so that, for example, university

researchers can get access to simulators and to the industry.

But apart from that, there is a tendency to think that if one has a particular problem, let's say that there are too many displays in the control room, that you solve that by saying all right, let us go to CRT display driven by computers, and because we only have six of them and therefore it is going to be a smaller control room and therefore it will be easier for the person to work with, and think that that is all that will happen.

Now the coupling between changing any one thing in a system of this complexity and what happens at other levels should be apparent to anybody who has ever been involved in a city where somebody has built a new expressway with the aim of reducing the traffic flow. There is a tendency for people to think that if you have a complex system and you change one thing in it, what you have is the old system with one change. You don't. What you have is a new system, and where there is, where it is highly complex, large number of sub-systems tightly coupled, you simply cannot tell what the new system is going to be like. You build the expressway to reduce the traffic. What happens? You now have double the number of people commuting in from the suburbs who never tried to do it before into the core. Generally speaking, as soon as you build ring roads, the total amount of traffic goes up and the traffic problems gets worse, all almost without exception I

think. In road planning that has been found.

The point we are making, that is a general property of large, complex systems. When you change something, you are changing everything. If you move from hard wired control rooms to soft wired control rooms here, you are changing the number of people you need, changes the way they will directly interact with the system, the kind of operating procedures you need. You probably are going to be changing, you may have to consider changing shift work and certainly have to consider changing maintenance and changing training, and that means that management is going to be affected and that certainly means somebody is going to have to go back to the regulatory Commission and ask that they are allowed to do things in certain ways. You cannot change any one thing without changing the rest.

MR. EBERSOLE: System interaction is a standard part of your business?

DR. MORAY: I think, yes, I think so. Research should be seen in this light. One of the things we say specifically is that wh somebody does a piece of research, they should be required to--

MR. WARD: Do you have a question?

DR. LEWIS: I did. You don't have to go back. I just want to ask to what extent what you have just said is universal. I really have two questions, because it must

depend a great deal on the internal stability of the system whether making a change propagates through the system or is simply contained.

A friend of mine who worked for a long time in the Pentagon at a very, very high level claimed that it was like a giant inflated balloon. If you put your finger in, you could make a dent. When you removed the finger, there was no sign the dent had ever been there, and this is an example of a stable system which is almost impossible to move, so one must know something about the local dynamics of the system to know whether a change--there are examples on your side, of course. Who would have known that the invention of television would completely corrupt American politics? That was probably unpredictable and yet it did happen, so one really must know something about the system. There is no universality about the rule that if you change something, there won't be any effect.

DR. MORAY: It is certainly true I think very large systems tend to have ultra-stability. There are many ways, you can kick it in many different ways and it will find a way of coming back to its initial starting point.

DR. LEWIS: That is correct.

DR. MORAY: But if you add something to the system, I mean that's if you put a disturbance into an existing system, but if you actually change something in the system,

the point I am making is that if you have a sufficiently large, complex system, you simply are not going to be able to tell very readily.

I would accept, I think the point you make is absolutely sound. What we are saying is that part of the thing, that one must stop thinking about what amounts to quick fix, local fixes in the system. You have to realize if you make a change in the hardware and control room, you may be changing management. Make a change in management, you may be changing the maintenance.

DR. LEWIS: I agree with your general concept. I am only wondering how universal it is.

DR. MORAY: I think it is also fairly universal if you radically change something, add parameter to the system, you get a different system. It is very difficult to predict properties.

DR. LEWIS: That it is difficult to predict is certainly universally true.

Could I ask one other question while I have you? Back to the old comment that management can make or break a system, we always say that, too, it is kind of a slogan that we have that concern for quality originates at the top and propagates through the system.

Again, I wonder how universal that is because one can imagine four sub-categories--active management, and

passive management, and top management and middle management. And there are certainly many organizations whose quality is more or less independent of the top management. That is, top, some companies don't even know who owns them from one year to the next, so it has a certain amount of irrelevance. And passive management is sometimes the best thing that can happen to a company even if, especially if it is inept. It is better that it be passive, and again there is a slogan among the military people that generals are only important if you are losing the war. They are irrelevant if you are winning the war. Their purpose is to recover from defeat.

I wonder to what extent there has been research that clarifies various sub-categories of management?

DR. MORAY: There has been considerable research in the military context. And in fact, one or two of the people in our panel, for example, Laporte is active in this kind of area. There has been a lot of research in various industries. The thing that is, one of the things that is striking about the nuclear industry is that you, if you look around, you find that there are a number of plants where they have very similar hardware. They have the same kind of reactors, roughly the same age more or less, the same kind of control rooms, although one of the problems is, of course, they aren't identical. They have been running for about the same length of time. If you look at the availability and the safety

record, it is wildly different, and it is very, you know, one faced with that sort of data, one is inclined to say that at least the possibility that what is going on has something to do with management policies should be looked at.

DR. LEWIS: That it should be looked at I agree, but I wonder, it is always easy to blame it on management and there may be, for example, I can give you countries of comparable size, gross national product, and some of which work well and some of which don't, and it is very hard to pin down just why that is the case.

DR. MORAY: Yes. I don't think it is necessarily easy, but in so far as when people use the phrase human error, they almost always mean operator error. We are arguing that the time has come to consider the possibility that it is not operator error, that operators do remarkably well considering the systems that they are trying to control.

DR. LEWIS: I agree with that.

DR. MORAY: If operators are good and working well, you still are have troubling, then it is probably not there that you should do the research.

DR. SHEWMON: Pilot error causes all airplane crashes!

DR. LEWIS: As in that case, I am trying to abolish the term pilot error and operator error from the language because to think of operators only in terms of their negative

potential is a one-sided view of the role of operators.

DR. MORAY: Certainly.

DR. LEWIS: As with pilots.

DR. MORAY: Yes. In many, I mean we are simply arguing that viewed from a systems--there has been too much--human factors or ergonomics when it is understood by the public at all, it generally is thought of to be knobs and dials and chairs and tables and work schedules, and while 30 years ago there might be some truth in that, that is not true now. And even if it were, we believe that a human factors program should not restrict itself to the traditional human factors but must include things like industrial sociology and industrial psychology, social, study of social interaction, and we want to urge NRC that in its research program it should include those kinds of features.

We believe that there are certain things that should be done, changes made in how research is done. Certainly it would be worthwhile trying to interest a wider research community in taking part in this, for example, universities and so on. Also staying for a moment with the idea of systems, there is a tendency for people to give highly specific results in their research. Suppose I were asked to do research on computerized operating procedures, which is quite a likely topic to come up. In the past, there has been a tendency for people simply to take a, to do experiment and

say look, here is what happens if you have your procedures on the computer, here is what happens if you have them in bound volumes at the back of the room, and this is better than that.

We would like to see NRC put a lot of pressure on their researchers when they are reporting thoir results to do so in such a way as to put it a systems context and say furthermore, you know, let us suppos[illegible] hypothetical thing that they decide that computerized operating procedures are better or seem to be better. That's, nobody knows if that is the case let me hasten to add. You don't just say that. You should say this particular implementation seems to be better and if it were to be implemented, we must point out that it would require decisions about how many computer screens you have in the control room. It would require, have the following impact on training. It would have the following impact on manning levels, the following impact on management, management will have to make the following kind of decisions when they implement it.

In other words, we would like to see research seen by the people who do research in the systems context, not simply as a fact which they have discovered because one of the things which worries us greatly, there is this huge body of research at NRC and it clearly is not having much of an impact on industry. The information is not getting transferred out, and part of that is--there are a number of reasons.

One is that NRC's own cataloging system doesn't allow it. The people who helped us, Tom Ryan and Dan Jones, went to heroic efforts to enable us to know what that list of publications is because they don't have an organized data base in which they can access information. If they don't, it certainly is not going to be used by anybody else.

And there is a good body of research. I mean I think a lot of research that has been done by NRC in the last few years is very good and potentially valuable. Where EPRI research gets into industry, it seems to be the case that NRC's doesn't.

DR. SHEWMON: I'm on various mailing lists and one of these comes from DOE who obviously spends a fair amount of money on data bases. I will get thick books on more than I ever wanted to know about waste management or whatever else.

How about DOE's system on operations research or whatever you want to call it?

DR. MORAY: I don't think--well, I think what we would like to see is some efforts made to really coordinate activity between NRC, DOE, EPRI, INPO, because something like an improved data base, joint data base management system for research is something where there could be cooperation. It is in no way going to decrease the rigor of regulation. It is going to improve the flow of information, and it is going to get rid of some of the adversarial, a small step in getting

rid some of the adversarial aspect of regulation. One can't help being struck by the possibility that, the intensive adversary relation between the regulator and industry that has grown up. It harmful in the end to safety because it is a climate that tends to lead to the industry merely satisfying the letter of the law because it is so much trouble, and we would like to see steps taken to reduce the adversarial relationship.

Now we do not want to see the rigor of regulation reduced, but we want to see perhaps the way it is done, ways explored whereby more cooperation and certainly some kind of cooperation between the various agencies all of which are doing similar work or related work should be improved.

We found cases where, I mean I know of one case, there is a field where I am particularly interested where there are, three reports on how to do task analysis were commissioned almost within a few months of each other, one by DOE, one by NRC, and there was one other one at the time that I was looking into this. It appeared that none of them new of the existence of the others. Now there may have been very good reasons that they were all commissioned simultaneously, but--and I am not entirely in favor of excluding all duplication of efforts. Sometimes that can be valuable. One does feel there is less cooperation between the various organizations and agencies than there could be.

MR. MICHELSON: Well, I'm sure you must appreciate there is an overwhelming amount of information generated in this country in the nuclear area that is fed out to the utilities. The point is that is one of the problems. The utilities are overwhelmed by the information input, and in their own processing and application is the problem. We don't package our information well. It is yes, there is three or four, five different people, organizations working at a different area. Each one will give a report to the utility, and it is a problem.

I think you ought to put more emphasis upon making sure that what you do is packaged in such a form that the utilities can use it. You have got to whet their appetites to show there is really something here they can use, and rarely do I see research reports that whet the appetite of the user. They are highly academic, don't seem to relate to the real world, although if you think about it a while, it does, but the utility doesn't have the time to sit down and think about whether or not this might be useful.

DR. MORAY: I agree completely. The industry, EPRI does it quite successfully I think.

MR. MICHELSON: They do a better job than most.

DR. MORAY: And I think if the NRC's own research could be brought up to the standards of EPRI as far as transmission to industry, that would be a considerable step in

the right direction, but I would like to see assumedly more, the panel would like to see more cooperation.

You know, it is very obvious that two great a cooperation could be seen by the public as being weak regulation. We are aware of that, and we know there are constraints both in the kind of research that can be done, the degree of cooperation that can be done, and we are sensitive to that, but nonetheless, we feel there are areas such as improved transmission of research and so forth where that can't possibly have a bad effect on regulation and is likely to have a good effect.

MR. MICHELSON: You are going to have to, you are going to have to convince the research community that they have got to develop a salable, they have got to do a sales job on their product, and it seems that they are not overly-interested in that aspect.

DR. MORAY: Well, that's true. I mean I think university researchers are not used to doing it very often, although considering the number of my colleagues that seem to have private consulting companies, that is a bit strange, and I guess consulting companies are interested in getting the package out the door and the check in, but I agree with that completely, and as a matter of fact, as I worked through our specific recommendations, you will see that we want to pay some attention to that.

So what I think I will do now is begin to go through our major recommendations, and any of the points that I have raised so far I will be quite happy to come back to later on.

(Slide)

DR. MORAY: The most important thing is that NRC make a firm public commitment to research in this area. If--the fact that they have cancelled their program of research two or three years ago, if I were in industry, I would take that as a signal that I needn't bother about it any more. Clearly if NRC isn't concerned, I don't have to be.

We are delighted to see that they are starting up again, and we strongly support their decision to start the program again. There are going to be problems because now with the exception of a couple of people present, they have lost I think all of their human factors people, and if I were a human factors--I am a human factors person. If I were looking for a job, as I am not, I would be very chary of taking a job with the NRC human factors program because I know that on its past histories, it has not been supported well. I know it was cancelled, and if I am going to comm.t myself as a senior professional to that thing, that is not an attractive undertaking. I think they are going to have difficulty in attracting good people. Most of the good people have gone to other places and I think it will not be possible to get them back.

There is one thing in particular we feel is important, looking at the past histories of the program. There has been several conflicts of interest between short-term research and long-term research, between research on the regulatory side or requests for research on the regulatory side and research plans in the RES branch which we feel that it is very important that research must be continuous, relatively small amounts of money, but a program sustained over a long period of time is going to be more effective than flinging a limited amount of money at the problem for two years and closing it down again, and that also goes for the local control. That is, it is undesirable that if the, if RES has started a program, that they should be interrupted at the short-term behest of the regulatory side and made, and have to stop their program and divert effort and funds into a short-term problem.

Now it is quite clear that there are short-term problems which have to be, have work done on them in order to solve the immediate questions. If somebody comes up, as they are likely to do, with a new piece of equipment, for example, somebody comes up tomorrow and says I have a certain system which I want to put into the control room, can I do it, then there is going to have to be a quick decision made and that means research is going to have to be done on certain systems or whatever, and that suggested to us that in fact the

research program should be perhaps split, that these responsive questions should be run out of the regulatory side and the long-term sustained program, building up the knowledge base for regulation and safety should be done out of the RES branch, and to some extent these should be separated. That implies, of course, funds for research done by the regulatory side. Also implies increased staffing. There is going to have to be increase in staffing anyway if they are going to run the program at all because they haven't got enough people to run it at present.

More importantly, we came to the conclusion after talking to a number of people and thinking hard about it, that if there is going to be a viable human factors program, it should have a branch head of its own. We are not saying that the person who is the branch head needs to be a psychologist who has done human factors professional training. There are many people now who are engineers who have come from, who have acquired sufficient knowledge and skills in human factors over the last ten years through working in national laboratories, working in consulting companies, working indeed in industry, and interacting with human factors professionals that they are now certainly of a sufficiently high standard and sufficiently knowledgeable to take that position, but we do feel that if human factors is a subdivision of some other branch as presently it is being run out of reliability, that is not

adequate to sustain a good program.

Let me say immediately this is in no way a criticism of the reliability branch's program, or how they have their interaction with human factors. We simply believe that from an organizational point of view, just as if a cohesive sustained program of research is to be mounted, because of the structure of NRC and because of the way the budget is handled and the lines of decision-making go, it is essential that any program which has a major impact on safety should be a branch and should be run by its own branch head, not a a subdivision of some other branch which basically has a different mission. That's implicit in this particular summary. It is spelled out in more detail in the, in the report.

Secondly, as I said before, we want to emphasize that people should adopt a systems oriented approach. Also we have tried to say, I think we have not said it quite as explicitly as we should have done or we haven't repeated it as much as we should have done, that when we talk about research on human factors, we mean particularly operational level. We also mean maintenance.

There is little doubt in my mind that, and I think in the panel's, that maintenance is a very serious source of human error. Maintenance people on the whole are less well trained than others. The conditions under which they work may be not all that good compared with operators. Their

qualifications are very variable across the country. Some utilities have their own maintenance people. Some appear to contract maintenance out. They may be using maintenance people who are qualified in a different state and may be absolutely no way of tracking the qualifications of the individual maintenance workers, and that cannot be good for a high-level, high quality maintenance program.

We would like to see--whenever we say operation, we include maintenance throughout this report. We think it is very important. That again is something which is being I think accepted worldwide in the nuclear industry.

DR. SHEWMON: I certainly agree with your comment on the need to have emphasis on maintenance. Systems oriented approach sounds like one is in favor of motherhood but doesn't mean an awful lot more to me.

System oriented, do you mean maintenance is important, or you should look for ramifications or what?

DR. MORAY: You should look for ramifications. Obviously it is important. Going back to what I was saying a bit earlier, I suppose sort of classic in a way Three Mile Island gave you the classical case for the maintenance problems, that perfectly good equipment, equipment that is in perfectly good operational state, can be left in an improper state as a result of maintenance. Maintenance work, goes and works on it, leaves it in a valve closed that should be open,

power off that should be power on, and because--the systems approach is not just motherhood because it says that the point at which research is required is the coupling between operation and maintenance and management.

How can you ensure that the people in the control room know exactly the state of the plant given that maintenance is finished? What kind of communication is there between the maintenance teams and the operator? Are the maintenance people simply regarded as slaves who come in and fix things and see themselves as that, or are they seen actually as an important component in the system? Do the operators care about the maintenance people and the way they do their work in such a way that there is a strong relationship with them? They understand that the two of them, the maintenance and the operators, are entirely dependent upon each other for the way the plant works?

There is a famous picture in the, one of the EPRI publications back there about 1977, '78, when Lockheed Corporation looked into the design of power plants, maintainability, which shows a picture of a maintenance worker sitting on the floor with a manual in his hands. The caption is this is the only case in which a maintenance worker was seen to consult some procedures.

And I think we don't know, we don't appear to be, either we don't know or don't appear to be using the knowledge

as to how to get the best quality maintenance out of the maintenance workers and how to couple the quality of maintenance to operation. It is not isolated. This is what I mean by systems. That it is absolutely classical that you get faults where the, something is indicated as incorrect in the control room, maintenance people go out, they work on the wrong unit, wrong train. We are told by NRC that that is the most common failure of maintenance is wrong unit, wrong train maintenance.

Now that shows that there is something wrong not just with the labeling on the plant, but there is something wrong with communication. They shouldn't go to the wrong unit, wrong train. Probably a basic ergonomics, they would be able to tell that they were working on the wrong unit, wrong train. And somebody ought to have noticed when they were doing that back in the control room and management when they signed it off. Clearly there is, when you get failure of communication like that, you are talking about systems problems.

MR. EBERSOLE: In fact it is only in recent months that maintenance is surfacing as a matter of safety interest. I am going to be astonished if NRC and ACRS even takes significant interest in that aspect of safety.

DR. MORAY: I mean it is clearly--

MR. EBERSOLE: It is dull. It is dog work.

DR. MORAY: That's right.

MR. EBERSOLE: No matter how significant, if it is dull, it is tossed off the table.

DR. MORAY: Well, I think there is enough, there have been enough catastrophes on various scales in the last few years at chemical plants around the world and so forth, it is now, my impression in talking to people in Europe and Canada and the States is that everybody is beginning to realize the importance of maintenance and there is, climate is shifting. I think what you have now got to do is sell it as an interesting research topic to people who might want to do it, and that may be difficult because as you say, certain aspects of it--I don't think it is dull when you get problem of that severity. It is interesting.

MR. EBERSOLE: The common attitude, that is the janitor's job almost.

DR. MORAY: That's right, and that is a recipe for catastrophy.

MR. EBERSOLE: There is a cultural problem. It is a career problem there.

DR. MORAY: Yes. Incidentally, one thing that we mentioned that I would like to say is that there is a, one tends frequently to look at other countries to see how it is done there. Whether it is regulation or maintenance or whatever, I think that is very difficult to do.

One of the problems about research in this industry is that if you look at France, you look at Britain, look at Canada, look at Japan, it is not at all easy to decide what you can learn from their experiences. One should not underestimate the cultural differences between the way people work. I have been struck by the fact that frequently in the United States I hear that operators complain about how boring the task is. Now the funny thing is in Canada the reactors are run by computer, and all the operator does is acknowledge alarms on the computers, and yet I don't hear Canadian reactor operators saying it is a boring job despite the fact that they do these in a sense more than the American operators.

And I asked some operators in Britain a few years ago whether it was boring. They said no, it is very interesting. And I suspect that this reflects national characteristics. It may very well be the case that Americans like to feel that they are in the action the whole time and therefore if they have got a building that is running smoothly and doesn't have to be tweaked the whole time, it is a boring job.

And I think there are more, I think there is more importance in national characteristics than one is sometimes inclined to admit so I think it is difficult to learn. One has to be careful about the lesson we draw from other cultures. You may remember that I think it was Oscar Wilde

said America and England were would countries divided by a common language.

MR. EBERSOLE: Can you translate some of what you say about the aircraft industry, aviation and pilots?

DR. REMICK: I'm sorry. We can't hear you.

MR. EBERSOLE: Maintenance in the aircraft and the tendency to look on the pilot as the focal point of troubles.

DR. MORAY: It is the irony the more automated a system you get, the more you put computer in, robots in, the more the system becomes autonomous, the more it is clear that human error is going to be maintenance error. Ultimately in the turnkey factory the only human errors are going to be maintenance errors, and as soon as you start thinking about that, and reflect upon the fact we are upgrading systems, including nuclear plants, more and more automation, it is clear that a major thrust toward maintenance has to be made because the more successful you are modernizing the plant, the more dependent upon maintenance you become and the higher the qualification the maintenance force is going to have to have to deal with it.

MR. EBERSOLE: Would you be interested in approaching the terrible problem that we have never solved about when do you automate and when you do not and for what reasons?

DR. MORAY: That is an interesting research topic,

and it is certainly one, it is one that some people, including myself, are actively working on, not surprisingly few people are. It is not an easy question to answer.

MR. EBERSOLE: I know that. We certainly haven't answered it.

DR. MORAY: No.

DR. EBERSOLE: Not even close to an agreement.

DR. MORAY: I think that is true. I think we don't know enough at the moment. And the problem is that you used to be able to appeal to something like physics laws--this is what humans do, this is what machines do best. That is becoming obsolete.

MR. WYLIE: I gather from what you said in your opening statements that you did not undertake to consider future designs?

DR. MORAY: No, we did not.

MR. WYLIE: However, the thing he is talking about, of course, is when you automate, when you do not automate, is something for future designs primarily.

DR. MORAY: Oh, yes.

MR. WYLIE: Also the plant can be designed in a number of ways to facilitate maintenance, for example, the German approach of four trains, so that you can take any train out for maintenance, and not affect your operations. You also design in on-line testing that does not affect operations.

things like that, that we don't do a lot of in this country. It would seem to me, of course, our Committee is facing, there are a number of advanced designs coming before the Committee that are seeking certification in the next few years, so it is very important that we look at those things.

DR. MORAY: Yes. Oh, yes.

MR. WYLIE: And they are human factors related.

DR. MORAY: Yes. Certainly; we heard from DOE about the inherently safe reactor design, and there was some, some hint, people were talking about having four small reactors run by one operator. This may be inherently safe, but that doesn't mean there are aren't human factors that have to do with, to do with workload, operator workload estimation, bordome if you like, shift problems and so forth. Yes, I mean the fact that you are going to more automated system doesn't mean there aren't human factors problems.

There are, however, unless you have a turnkey factory in which you switch it on and nobody ever goes in, then you push the human factors problems back to the design stage, and I think it is very important to remember that debugging software is probably harder than debugging hardware. As far as we can find out, nobody knows how to debug very large software systems.

I was talking to the person at Ontario Hydro a couple of years ago who is responsible for the software of the

Darlington and Pickering, and the way you debug the very large complex software systems, you try them out and when you find error, you fix it, try it out gain. You fix that. And you come up and curve toward performance where there don't seem to be any errors. When you can't find any for a reasonably long time, you say that is probably okay and then you use it, and you do not know whether three years down the road buried somewhere in the software there is something waiting to happen. Someone called it the pathogen in the system, an accident waiting to happen. And it is probably impossible to find them. I think it is literally true that given a sufficiently large software system you cannot guarantee, there is no way you can guarantee to find all the flaws in the software. Then you get into problems of how--this is getting a bit out of my field. I am not talking about the report. I am beginning to talk about some of my own opinions.

DR. SHEWMON: There is levels of flaws, too. There is the question of whether something goes to the wrong place or whether somebody by making a mistake can get you, how people can mock-up is something you are more familiar with the variety of than most.

DR. MORAY: Yes. There is another problem in a system sense about the software, and that is the way, what tends to happen these days because really first-rate software people are hard to come by, bit the first bugs are fixed by

one person who leaves the company, works for somebody else, and the next few are fixed by something else and he then leaves and three or four years down the road you have got patches all over it and nobody actually knows how it works anymore. And you can never get the people back, and it is, you know, there is a sense in which it is probably neither debuggable nor fixable. It seems to be engineering solutions.

You commission separate, two or three separate sets of software and two or three separate sets of hardware by different computers, literally different; instead of having two FAXs, I have a FAX and CDC or something, and then you get software written by two different companies to do the same work, so it is rather unlikely that the factory which sends down a particular software package on a particular hardware package will simultaneously send the other software down on its hardware package when they are not actually physically the same.

DR. SHEWMON: You are suggesting this is a way to take care of common mode failure if say we have got redundant loops, one is completely different from the other one at least in software and computer?

DR. MORAY: That's what I am saying at the computer equipment level. I am not a computer science expert, but I cannot see how else you are going to guarantee real redundancy.

MR. EBERSOLE: But the--

MR. MICHELSON: The hardware is suffering from the same problem. At the same time it has also been patched by people who have now left and other people don't realize that the bug is built into the hardware particularly in control systems.

DR. MORAY: Maybe the lesson, maybe the lesson is simply redundancy is not all what it seems to be.

MR. MICHELSON: It may not be.

DR. MORAY: One tends to rely on, and actually I'm sorry, I am getting way away from my presentation. I think one very important thing to remember is that even if redundancy is all it seems to be and hardware, that if you put two humans side by side, if you multiplex two humans, you don't get the same effect as multiplicationof hardware. If you have two people, one of whom is checking the work of the other, that may be better or worse or no different from having one of them because what, the first one may think is wrong if it is going to be checked, I don't have to pay so much attention to it, and the second one may think since he has done it, I don't have to check it all that well, and there may be status problems as to one sees the other as his superior, and/or whatever, and you really cannot tell. There is absolutely no way that if you take the probability of human error as being P, if you have two humans, that it is P squared

and so on; absolutely not.

DR. LEWIS: I have some long, some experience with large software programs and there it is almost always the case that if one programmer checks the work of another programmer, he will not find the errors, but if you take a programmer who has never been exposed to the subject and put him in the dark room and force him to do it over again, the answer will turn out different, but people cannot check other people's work. They can only do it themselves in the software business.

DR. MORAY: I this that is a common experience. It is almost never possible to use somebody else's program. You always end up writing your own.

DR. LEWIS: Back on the subject of redundancy, in this agency there seems to be a little bit of confusion between the word redundancy and the word diversity. At least I think there is some confusion, and the question of diversity, you mentioned it in the context of software, having a completely different program, parallel, is a tradeoff because sometimes it is better to have technical redundant components. Other times it is better to have diverse components. Depends on the failure rates, and the degree to which you have compromised yourself by going to diversity. It is by no means a trivial question.

DR. MORAY: I don't think it is. And it is not a trivial question when you are talking about humans.

MR. WARD: Why don't we take a fifteen-minute break at this point?

DR. REMICK: Reconvene at ten minutes after ten.

(A brief recess was taken.)

DR. REMICK: Can we please reconvene, Mr. Ward?

MR. WARD: Okay. Neville, continue as you will.

DR. MORAY: With your permission, I will get on to the, some of the substantive recommendations that we have, we wish to make in the record.

The first one has to do, to do with how research should be conducted, and there are a number of topics that we want to raise here.

One is that a lot of research in the past has been run through and by the national laboratories who have done a very good job, but we would like to see the research community extended to try to bring in more people from universities and other research institutes.

We also think that the quality of the research would be improved by peer review, and we think the peer review should occur not just at the end of the research but actually at the time when RFPs are prepared. It would help--the NRC human factors group has suffered from being very undermanned and overworked, and I think that one of the reasons that they have had to use the national laboratories as intermediaries in running their research is because of that.

Now the trouble is that that's wasteful of funds because everybody is creaming off overheads as you go down layer after layer, and also really it would be preferable that the NRC should manage its own research program. For that they need more people.

But they could make use of we feel something rather like ACRES but just for the human factors, and I believe I have heard that Mr. Beckshard may be in fact implementing something like that, sort of an advisory group on human factors so that at the time that research problems were formulated and an RFP was sent out, that would be subject to peer review. The bids would be subjected to peer review, and the reports at the end of the research would be subjected to peer review.

This has been done once recently in their programs with I think considerable success in a program of research on modeling the human errors, how human errors arise. That's a standard way of getting good quality research out of the research community. It wouldn't be particularly expensive. I think you could get people, find enough people who had, were prepared to give their time in the public interest to do this.

DR. LEWIS: I note with some amusement your vugraph says you recommend involving a diverse group of knowledgeable people, but you don't say anything about redundancy.

DR. MORAY: Yes.

MR. WARD: Every committee is redundant.

DR. MORAY: The thing is that one thing that the peer review process might be used for is in fact to try to get the research to ensure the research is slanted toward usefulness. I would like to see that done. There is a tendency if you get universities involved in doing research--maybe I can put it this way, that the panel felt that it is important to see the results of research not just as the accumulation of facts. I will come back to this when I talk about PRA work, but essentially the reason for doing research on human factors in nuclear power safety is to see the existing situation as being one which is sending out signals, even think of it in control theory as signals, that the existing situation sends out signals saying there is something wrong with the system, all right, accidents, incidents, and the point of research is to act to take these error signals if you like in a closed loop sense and generate appropriate control actions.

Research is not just to acquire information, and in order to get academic, university researchers particularly to really work in that context, I think the peer review would be one way of doing that. Peers may be not just academic, also be people from industry, to help NRC's small human factors staff to monitor the quality of the research. That's--yes?

DR. REMICK: What is the evidence to the first

sentence of your second paragraph there that there are barriers to accessibility to simulators?

DR. MORAY: It is quite, well, it is quite simply this. If I want to do research on human behavior in the operation of a nuclear power plant, I can do it at about three separate levels. I can take a very small and specific problem and do it in my laboratory. I can use my IBM PC or work station or whatever and simulate a part of a display. If I want to find out, for example, whether one kind of display is more legible than another, whether analog display is better than digital displays, I can do that in the laboratory, and I can do it sufficiently well to be sure that my results will transfer to a real situation.

If I want to do research on what happens over an eight-hour shift when people are controlling a real, something like a real plant with two or three people involved, and the kind of interactions which are involved in a real nuclear power plant, then I need something which embodies the properties of a real plant, and that's a simulator. That's the other extreme. In between there are part task simulators and so forth.

DR. REMICK: It is a very strong statement--there are barriers to that, and that sounds as if somebody has been turned done. I am wondering what evidence there is that people have been turned down trying to get access recently.

DR. MORAY: I have talked to utilities once or twice and said you know, I have certain research topics which I would like to investigate in connection with this, and the topics seemed to them quite sensible, and the answer is--is there any chance of being able to do it on your simulator? And the answer is no because we use our simulator every day all day for training, and licensing, and it is just we simply cannot provide you with a time. It is so expensive to run, and it is so heavily used that we can't set aside time for research. Now I am not saying it is impossible.

DR. REMICK: Is this in recent years?

DR. MORAY: Oh, yes.

DR. REMICK: Has any effort been made to utilize the NRC simulators?

DR. MORAY: They don't, they don't--

MR. WEISS: No. We just acquired them. They have not been used for research at all.

DR. REMICK: Might they be?

MR. WEISS: It is possible, yes.

MR. WARD: I guess one problem with that, of course, is that for at least some of the research you want to do, you need not only the simulator but you need a crew.

DR. MORAY: That's right. By barriers we don't mean malicious barriers or barriers of ill intent. We just mean that in fact, you can't get at them, for whatever reason. The

facilities are not available. I mean there has been talk of a national center for either nuclear human factors research or complex systems research.

DR. REMICK: The thing that worries me, by that you have the simulator, maintaining a simulator up to date is a continuous problem, and you talk about crews. If you are going to have a national center, you are not going to have knowledgeable operating crews, so it seems to me that utility simulators are the best. I do know of cases where utilities are making their simulators available for removal or even for university course work, systems courses and so forth, so some utilities are doing it. I was just wondering how widespread the barrier is.

DR. MORAY: On the panel when we--it was felt there were several of us who were interested in doing research, in selling people from the university or research groups in a vender supply and so on, and up until now, say a year ago, the feeling was that it was extremely difficult to get access to simulators of this kind.

What we are saying is that there is a real, already two kinds of problems of transfer of research. One is if I do it in the laboratory, it may not work in the real world. And that's notorious. I have to, I do, personally I do research on fairly high technology process control type of topics. It is, by my standards, the work I do is expensive, slow, and

difficult, and I think some of it will transfer to real life tasks, but I am not sure. At some point or other I will go to somebody with a simulator and say I have got all this work done, now I would like to try it out in a real situation, can I use your simulator, and they may say yes. That's a sort of intellectual problem of transfer of results.

Whether the laboratory results generalize to the real world; in human factors research, it frequently doesn't unless you are very careful how you do it.

The second reason for wanting to get access to simulators to do research is I think plausibility. If you want the industry to believe that there, the results you find actually will make a difference to their plants, it is much more convincing--

DR. REMICK: I am not questioning the need to use the simulator. It is a question about whether there is access or not, and I think one way, that experimenters have to get the utilities or the industrial organizations interested in research so that they would help make those facilities available.

DR. MORAY: I agree completely.

MR. MICHELSON: Have to do a sales job.

DR. MORAY: Absolutely. In our report, we suggest in fact that organizations like NUMARC and INPO could be sort of brokers between the university community and NRC, that if

NRC--another way of getting cooperation in less adversarial things which is not going to in any way imperil the quality of regulation is to, for NRC and INPO and NUMARC to get together to provide research help, to provide research facility access for the people doing the research.

You know, don't forget it is only recently any simulators have been around. If you are talking five years ago, you won't have had access because there weren't any.

DR. REMICK: It was why I asked for recent evidence.

DR. MORAY: It may be getting easier. But it is not easy.

DR. SIESS: Again, with relation to this slide, but another aspect of it, with reference to peer review, in another area of research where the NRC had been urged to get peer review of research, reports of research results, the NRC response has been to direct the researchers to publish in referee journals.

Would you consider that an adequate form of peer review?

DR. MORAY: No, I wouldn't. That's an adequate form of peer review for ensuring that people get tenure on the basis of the research they have done for NRC, but that's not really the issue.

The issue is peer review which both ensures the scientific quality of the work, and also ensures that it is

seen as relevant to the solving of industrial problems, and those are not necessarily the same things. I was saying during the break that we are faced at the moment with a rather bizarre situation where we have a professional journal called human factors, and now there is talk of founding a send one called applied human factors, and I must say I find that strange, because if human factors is not applied, what are we doing it for? I mean--and I think that really is a serious issue.

Another problem, of course, is is it the case that we have a sufficiently sophisticated group of human factors professionals who could peer review nuclear human factors work? And I think the answer to that is probably yes. There was enough, there have been enough people involved in the first few years of the NRC human factors program as consultants and contractors and research workers that we can find it. There won't be in another few years unless the program runs again, but yes, you could find people sufficiently knowledgeable to do it. They are not all that many, but there are enough. It will be better than not having any.

So these recommendations toward improving the quality of research.

(Slide)

DR. MORAY: Continuity, we do feel that it is more

important to have continuity than to have very large funding, not more than to have adequate funding, but certainly continuity of research is important.

NRC's human factors people have suffered from sort of on again, off again decisions. Programs get put on hold or cancelled and then started up again, and through pressures for various kinds inside NRC. That is not the way to do good research. You have to maintain the research community's interest if people are going, if the good people are going to go on bidding to do the research, and it is, a sustained moderate program over several years is going to be more productive than a few large one-shot projects we believe.

(Slide)

DR. MORAY: This, we have transfer of knowledge, we have already talked about. There is a large amount of human factors knowledge out there. It is not nuclear specific, but it is has to do with everything from shift work and organizational behavior down to knobs and dials in the control room. It is clear that that is, has not in the past been adequately used. That was documented by the EPRI studies of control room design back in the late '70s. Some of the new control rooms are now looking much better and have used human factors work.

In many cases, it is not research that is needed but application of existing knowledge, and to have that happen, we

have to improve transfer of knowledge from the data base to industry, to designers, and to management in particular.

We have some recommendations to how that might be improved, but clearly there is something not working well at present. The information is not getting transferred. Now again a few years ago it was quite difficult to find the data. Now there are a number of handbooks. There have been several handbooks published in the last two or three years. There is a major handbook of human factors information about to come out from the United States Air Force, and for basic control room decisions, there should be no problem at all in finding data now. There really should be no difficulty in finding data on things like shift work, and the research here is not content research, but research on better methods of transmission of information. We would like to see some methods done in that way.

DR. REMICK: In arriving at this recommendation, was there any consideration of whether the NRC should publish an annual review compared to possibly DOE or EPRI?

DR. MORAY: The reference to the annual review starts from the fact that NRC does in fact publish an annua review of its research. At least in the human factors, at least it did when it had it, but when you look at that, it is not in a form which would be particularly useful. If I were a plant manager, and I wanted to understand what new research

had been done which would help me to improve my plant, it is clearly a document to, for internal consumption, to tell the rest of the organization what has been going on in this past year.

Now we want to go beyond that. What we would like to see done is an annual review of research which is relevant to the need of the nuclear industry, not just research that is done by the NRC. Rather like the annual reviews of physics, annual reviews of psychology, annual reviews of pharmacology and so forth.

Yes, it could be done by any of those bodies. We don't really mind. In fact, we would like to see this as being a compendium of research which is relevant to improving human factors in the nuclear industry regardless of where it comes from. It should combine work done by NRC, by DOE, by EPRI, by psychology, by, you know, it requires people to scan the journals and find out all sources of research, and then write it in a form which would be let's say attractive to industry. That it would become--

DR. REMICK: That might be a function of EPRI rather than the NRC it seems to me.

DR. MORAY: Well, we do think that, we keep coming back to this in a sense, that there is no reason why EPRI--we look, in the report, we do discuss the possibility of EPRI, INPO, DOE, IEEE even doing research, and we spent some time

considering whether a regulatory agency should in fact do research, and we came to the conclusion in the end that yes, it should, because while EPRI's research is certainly of a high quality, they have done some excellent work, some of their publications are absolutely first rate, it is clear that their agenda is going to be strongly shaped by the perceptions from inside the industry as to what is important and what isn't, and INPO doesn't do research. It is not in its charter. And DOE has its own interests and its own job. And IEEE is not a research organization either, and when you go down this list, you are left with the conclusion that yes, NRC must direct research.

But we would certainly favor cooperative activity. The problem is if you give it to EPRI, in a year or three years down the road that EPRI doesn't, decides that it is worth doing, then NRC will have to take it back, should take it back anyway. We would not object to NRC coming to an arrangement with EPRI whereby EPRI would do it, but I think it needs pushing from NRC, and not just left it to EPRI.

Yes?

MR. SERIG: Do you envision a document something like Mil Standard 1472 where there is a custodian and that document under goes periodic upgrade where knowledgeable experts within the subareas of that document contribute to the upgrade?

DR. MORAY: You don't need a new document like that. There are enough of them around anyway. There is the Mil Spec 1. There is the EPRI volume on control rooms, there is the EPRI volume on design maintainability. There is the USAF engineering data compendium. There are lots of them around.

No. What we are talking about is simply a relatively small document, put out on an annual basis which summarizes research from all sources whether it is social, whether it is sociology, or an NRC contract on a highly technical problem like EOP design, and just is available. Each year a volume comes out and says look, here is a list and a short description of work that is, that has been done in the last twelve months or more likely to be year before that, which is of relevance and we think of usefulness to industry, to improve the human factors efforts, improve safety and productivity.

DR. REMICK: Would the questioner please identify yourself?

MR. SERIG: Dennis Serig, Liability Human Factors Branch of the RAS.

DR. MORAY: I wouldn't like to see a big volume. You just added little bits and I think this should be sort of annual.

MR. MICHELSON: Is this annual form that is produced in these other fields, is it prepared by people who have

reviewed these articles and are knowledgeable of how they might be applied with some then discussion of how they might be applied?

DR. MORAY: No. The existing ones, annual reviews of physics and chemistry and so on, are scholarly compendia.

MR. MICHELSON: What the industry I think needs in this case is something that the people who are already very busy can pick up and without too much additional effort at least find out if there is something here I need to know about and then it can go back and give you the detailed articles. If you don't whet their appetite, they are not going to pay any attention to scholarly documents.

DR. MORAY: They shouldn't be scholarly documents. They should be usable documents.

MR. MICHELSON: What I think the nuclear industry community needs is somebody who sits down and who understands all this work and who can convert it into ideas at least as to how it might be applied, and I, I like, that's the kind I would like to read because I don't have time to read more than that.

DR. MORAY: I agree completely. I am not, we are not--when I talk about research in this context today, I am not talking about scholarly research, to be published in archival journals. I am talking about research which is useful.

MR. MICHELSON: Scholarly research needs to be done, but then somebody needs to convert it into language and ideas understandable to the general designer or the general maintainer, whoever.

DR. MORAY: Yes. I have never understood why people think that is a particularly difficult undertaking.

MR. MICHELSON: It isn't, but it is not, it is dog work so to speak, and not, a scholarly individual doesn't want to get his hands dirty with that sort of thing.

DR. MORAY: I think it is quite fun actually.

MR. MICHELSON: You are perhaps the exception.

DR. MORAY: It is a worth, you get a lot of reward for actually--but I agree. It doesn't get you tenure.

MR. MICHELSON: Doesn't get the originality reward.

DR. MORAY: And doesn't get you tenure, and that is a problem, but it is, there are people who can do it. All we are saying is that we really need, there is no point in doing the research if it doesn't get used. We are not asking NRC to support basic research for the good of the research community. We are talking about a program which must lead to work which is not merely useful but used. Otherwise there really is no point in doing it.

So whatever I say, please bear that in mind. That's the, I may talk as if I am thinking about scholarly research of no particular use whatsoever, but that is not actually the

point.

Dissemination of nuclear industry human factors research, we do think that there is a need to improve communication, and in particular, there is a lot of useful information at NRC, at EPRI, at INPO. It is difficult to find it at INPO because as you probably know, you can't get at INPO unless you are in the industry. I can't get hold of INPO documents at all. If I ask INPO for a document, a couple of times I have asked for some of their documents which are excellent to use for teaching, and the answer is no, can't have them. You have to go to the utility. If the utility will get them for you, you can have them, but INPO is a closed book to the research community, unfortunately.

But it would be I think a step in the right direction to try to get some kind of coordinated bibliographic data base with NRC and the other agencies.

MR. MICHELSON: Human factors data base, is that what you mean?

DR. MORAY: I am talking about human factors data base. For all I know, the other ones exist.

DR. REMICK: When you say human factors data base, how broadly are you defining it? You told us earlier that it was a very broad definition including management.

DR. MORAY: At least, when--you could define it let's say at least to include those publications which have in

the past come out of NRC's own program.

DR. REMICK: How broad? Would it include management issues?

DR. MORAY: Yes. They have sponsored research on management issues.

DR. REMICK: You indicated it includes PUCs and regulatory--I am not sure how far you want this to go.

DR. MORAY: I want it to be one--

DR. REMICK: I think this is an excellent suggestion.

DR. MORAY: It really doesn't take all that much effort. It is trivial these days given the computer, cheap computing power now. And I would say that if I were at NRC, I would want at least all my own documents, all NRC's own published documents, NUREGs and NUREGs CRs, to be on the data base, with key words search. That is an absolute minimum.

DR. REMICK: You are talking about--

DR. MORAY: Yes. It shouldn't take--you know, if somebody comes to me and says can I have a complete list of all your human factors publications, it shouldn't take a relatively senior person days of his time to dig them out.

DR. REMICK: I guess I am still confused because human factors as you defined it includes things that you said environment. It goes out beyond the technical issues to the--I mean let me look at your chart. How far would you want

that because if you get too large a data base, then it is very difficult to use.

DR. MORAY: No. That's not true. If you have a decent accessing system, retrievable system, it is not difficult to use at all. I use Dialogue regularly which has thousands of journals on it, and I don't have any problem using it at all. It's just a question of will you get a good data base?

DR. REMICK: Suppose I--

DR. MORAY: I would say NRC should put all its NUREGs and NUREGs CRs into a data base with a good retrievable system.

DR. REMICK: Now I want to access human factors. How far do I go?

DR. MORAY: You say human factors, and it says we have 400 articles, and you say human factors and control rooms, and it says we have 20, and you say human factors and control rooms and procedures, and it says we have four and you say give me the abstract.

DR. REMICK: I am looking for the definition of human factors in that sense.

DR. MORAY: With a modern data base, you can work from the raw documents. If it is in the title or the abstract, the retrievable system will pick it up.

DR. REMICK: How about management issues?

DR. MORAY: You type management, human factors and management and nuclear power. That's what I do. When I get a contract, that's what I do.

MR. MICHELSON: This is heavily dependent upon writing abstracts that are pitched toward the system of searching. If you are going to device--abstracts aren't now prepared necessarily that way, so it is a lot more difficult.

DR. SHEWMON: Many journals have been having key words as a requirement for years.

MR. MICHELSON: And if you write your abstract, the key words, it is great, but if you are writing an abstract not having anything much in mind--

DR. MORAY: This is a sort of super human fallacy. You are saying it would be very difficult to find an article if it wasn't encoded in the right way, if I were looking it up on computer. It is not easier to find it if you are not looking it up on computer.

MR. MICHELSON: Anything is better perhaps than not having--

DR. MORAY: The existing situation.

MR. MICHELSON: Yes. But it works better, of course, once you know the system and then write the, and extract it from the system.

DR. MORAY: Now days you don't even have to do that storage. You can put the documents in.

MR. MICHELSON: I have tried those systems, too. It is an experience trying to figure out how to search such large data bases.

DR. MORAY: It is easier to search a large data base than a poorly organized large library which doesn't have the journals.

MR. MICHELSON: Always easier.

DR. MORAY: That is all we are saying at the moment. It is virtually impossible to find out the data and with very little effort and money it would become accessible to people at the push of a button.

MR. MICHELSON: NRC, there is even greater interesting source of human factor information, and that is in the form of inspector's reports, deficiencies reports and so forth, which again there is no way to search because they are not key worded into a search system. I don't think you necessarily meant to go to that extent, but I think there is some valuable information there that you just simply can't retrieve easily.

MR. WARD: I think we probably need to move on.

DR. MORAY: Right. Let me come to the specific research topics we have chosen. You may remember that I said that out of a very large shopping list we have decided, we have tried to narrow down the proposals and we have chosen a number of topics for immediate, which we propose as immediate

research topics on the basis of three criteria. Some research topics may have a critical impact on safety and must be addressed immediately. Some areas, research is needed as a basis for evaluation. And some research may be essential building block for long-term program, and in all cases, the research should be aimed at management, maintenance, and other ancillary workers as well as control room operators.

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DR. MORAY: The first area of research we have called human system interface design, and you have a second--were those the ones I gave you last might? They are just stuck in the back looseleaf; just before the conclusions there is an extra set of pages. And what I am going to do is, for example, this one, human interface, system interface design, what I am going to do is go into a little more detail than the last time I presented this work as to what the topics are.

MR. KRAMER: Joel Kramer, NRR--Neville, could you describe a little bit how the panel made the determination of what was critically important to safety as your criteria? What was the basis for the process?

DR. MORAY: Yes. We began by, we spend sometime essentially looking through the topics which NRC hadn't done research on, looking at the relative weight that had been put into work in the past, and looking into, considering what we

knew about recent incidents at nuclear power, and also going on the basis of our general, general knowledge of, since several of us have spent a number of years doing consulting or work in this area.

We felt that there were a large number of questions to which we would prefer to know the answers if we were, if somebody came to us and said how can I improve the operation of plants in this area, we asked would we have an answer for that?

After that we began to look at it in a different way. We said are there things, are there going to be innovations coming up where regulation may be required soon, and we feel that we do not know what the answers should be about this. And that led particularly to some of the questions on automation and computer developments, and we felt these were important, these were urgent because we knew that there were companies and venders who were working on certain kinds of innovation, particularly AI and computer-assisted systems and since they were about to start marketing them, it was important to find, important that NRC should have answers to problems about ensuing--because the utilities were going to come to NRC and ask permission to use new technical innovations, so that was the first criterion that we knew of, the existing technological innovation for which we did not know, for example, how to, how to assess them.

Other questions, the basic research, the long-term ones, we felt there were certain topics which were going to require a great deal of research, most of which would feed into making increasing safety, and therefore we better be started now and just kept going, for example, causal models for human error, so it was really, I think those are the two major things.

There were certain basic knowledge which we don't have, but it is bound to help, and therefore that research should be started and should be run continuously for a long time.

On the other extreme, there are certain particular topics which we know NRC is going to be asked about in the regulatory context soon, and therefore one should try to get the answers to those quickly.

Is that a satisfactory answer?

MR. KRAMER: Partially I guess. The question is for any of these things activity is ongoing, the question is how important is safety? How is it measured and how is it determined?

DR. MORAY: Right.

MR. KRAMER: And that detailed process from a technical standpoint I am still not sure how the panel dealt with that.

DR. MORAY: We did not sit down and say do we know

the probability of, the probability of human error of a particular kind? If we do this research, can we say that the probability will drop from P1 to P2 as a result of this research? Because frankly we don't believe in those numbers in the context of humans.

I think our feeling was that the research we proposed will lead to safer systems, maybe what our natural judgment, we may regard as qualitative judgment. We cannot say by what percentage it will change. Furthermore, nobody can. Furthermore, it is probably in principle impossible.

I guess the answer, I mean the real answer is that as with NRC, most NRC specialist panels working on topics like this, the reason those, the people on the panel are brought together is the feeling that their collective expertise and wisdom over the field puts them in a position to make a collective judgment where there is no, were there are no hard numerical criteria. If you had hard numerical criteria, you would not need to pay the National Research Council to do this work. I mean we are being asked to criticize expert judgment which later on puts me in an embarrassing position, but essentially are asking for expert judgment, okay. I think that may be the answer you are looking for.

In the field of human interface design, human system interface design, the most important topics we feel have to do with computer aiding, either computer based information and

display systems, and automation and computer based performance aids. The reason we feel that these are important is because they are examples of things which people are about to try to sell to the industry. They may be expert systems. They may be computed aided diagnosis, or they may be computer based operating procedures.

The most critical thing in this area is that nobody knows how to assess the quality of expert systems. I have done a little bit of work on certain systems myself and one or two other people on the panel have as well. It is remarkably easy to build an expert system these days with the software shells you can buy off the shelf. It is extraordinarily difficult to tell whether you have got a good one, and I have read no papers which convince me that anybody knows how to do, to tell whether you have got a good one or not.

I was looking at a paper that said validation and verification and assessment of expert systems yesterday, and it is garbage, and it is from a major journal in the field. It is clear that it is not enough as the academic criteria might be to show that this expert system behaves like a human because the reason you are putting it is it that you want it to be better than a human, but how you tell whether you have got a good one or not is totally unclear. Usually it is an existence proof. Switch it on and it gives you some expertise, but we do not know how to tell whether you have a

high quality artificial intelligence system to support decision-making, and we do not believe that NRC should get into the business of building expert systems or computer aids, or of paying other people to do some. That is a real black hole for absorbing money.

DOE has got some people working on certain system development. EPRI has people working on expert system development, and NRC should leave system development alone. Let other people do it. What they should do is develop research to enable them in a regulatory context to say whether or not a particular computer is good enough to be put in a plant, and that is a very important issue. It is going to come up for judgment very soon and we don't know how to do it.

On the operating side, there are also problems to do with computer aided displays, what are the best kind of displays, computer aided SPDSs, SPDS have become in fact a way of getting computers into control rooms which are basically in the States not computer oriented.

Operating procedures, there is still problems to do with operating procedures. The symptom based versus problem, whether or not they should be computerized or not. How to tell when you have a good, valid operating procedure; there are big problems in innovation. One of them is that if you give people a new piece of equipment with which they are to work, for example, a new kind of display, say the star graph

dis ays, for the, not the variant displays, one would expect it to take many hours or indeed days or perhaps even weeks for operators to become used to new equipment. And it is very, it is methodologically extremely difficult and very expensive to validate a new method, relatively trivial table top laboratory based experiment. I now have to find, I have to practice my subjects for say maybe several weeks, 10, 20, 30, 40 hours before I check my data on trivial table top simulation of small thermalhydraulic system. If I put in new displays, I want to tell whether it is a good one. Unless it is blindingly good compared to the old one, I would expect negative transfer effect, to take sometime for operators to learn how to use it and to give up their old habits. To tell what their behavior is going to be like in the limit is going to be difficult, time consuming, and that's not, that's a real problem for innovation. And one should I suppose require the venders of new equipment to show that they have validated the qualities of their displays. Certainly research needs to be done. There all these areas of human system interface design.

(Slide)

DR. MORAY: The second area is personnel sub-systems, and the main things here are maintenance, and enhancement of operational skill, improvements in the licensing examinations, and problems to do with shift scheduling and vigilance. I spelled that out a bit further in

turn.

(Slide)

DR. MORAY: We still need better methods of telling whether training is effective or not. There are a variety of new methods of training being explored in military contexts and in certain other industrial contexts. There is a, since we now have whole task high fidelity simulators, there is a tendency to use them. You have to train people on the entire system, may not be the most effective way. There may be particular sub-systems on which it is more effective to train people on a small simulator, part task simulator, to give them intense practice on subsections of the task.

The trouble is if you train them on a whole full-scale simulator, it takes a long time to run an incident, and you are effectively giving--the amount of time that they spend on a particular part of the training given that you are working with a full-scale simulator is relatively small because it takes place in the context of the entire operation, of the whole simulation. It may be that there are certain particular tasks, say some particular set of manipulations during start-up which could be taken out and put in a part task simulator which is very small, very cheap, put on a PC, give people intense practice on that particular sub-skill which is a particularly difficult one, and it would be far more effective to train that intensively on a part task

simulator and then transfer the training to a whole task simulator from time to time.

Exploratory, embedded training, exploratory training, there is this fundamental thing about how people come to understand the system they are working with. It may not, be that giving them drills on pre-planned incidents is not the most efficient way. There is the problem of training for rare ununknown events. If the trainer cannot think of an event, then he cannot train the trainee to cope with that event. And one needs to understand the fundamental problem of how you train people to cope with unknown events beyond design basis interests.

There isn't time to train people in one sense for all the design basis events, and in any complex system there are more ways of it going wrong than the trainer can think of. And this is a very important topic.

MR. EBERSOLE: In that connection, I think most simulators are unable to take the problem up if you postulate a failure involving total plant, of a single function which is critical, because the designers and the regulators have not required a presentation of a schedule of events which occurs when those unfortunate things happen, and certainly the computer is in ignorance of what happens and therefore the operator, but those things are quite available if you just search.

DR. MORAY: There are considerable evidence from LERs and actual history of events to suggest that the biggest problem for operators are not the large foreseeable events, large LOCAs. They are the problems where you get a number of trivial or even unnoticed plants of small sub-systems which really don't make my difference to anything until something else happens and then they discover there was a whole train of things.

MR. EBERSOLE: It takes two or three things in coincidence to really pile the problem up.

DR. MORAY: That's right, and it is, you know, the problem again is that to use a high fidelity, full-scale simulator to deal with those sort of problems is really taking an awful lot of time out of a very large system.

MR. EBERSOLE: Simulators simply aren't designed to cope with it. Whatever you put in comes out of them. You don't put those things in.

DR. MORAY: It is very important that whole task simulators should be present, because we know that skill declines when it is not practiced, particularly cognitive skills. Central motor skills, not too badly. I rode a bicycle for the first time in about 30 years, and after not riding a bicycle for 30 years you get on a bicycle, you can ride it. Maybe you can't ride it hands off around the corner, but you can ride it, but cognitive skills decline rapidly when

they are not exercised, and that's why the airlines use intensive retraining in full scope simulators, and the only way we know to keep up skills, to keep cognitive skills efficient over a long period, complex systems, is continuous training in simulators, and therefore it is absolutely essential to have some experience of full-scale simulation.

Operators distrust simulators which are not exact copies of the plant which they work on, for understandable reasons, so we are not saying that the money has been wasted. It hasn't--fundamental importance, they are there for training and retaining. Skill maintenance is keeping the skill up once it has got there. The learning curve is an astometric curve, but the moment you stop training, it doesn't stay up there. It continues to decline. And the only way to keep it up is by retraining at relatively frequent intervals, and so that certainly is an important thing, but one needs more research on how to deal with these other things, particularly how to train people for the unknown event.

It may turn out to be that you don't do the training on simulation. Maybe something else you should do.

MR. EBERSOLE: We have recently been inquiring and have found that postulating a total AC power plant, there is virtually no knowledge of sequential events that occur subsequent to that. Operator's ignorance of the first pinch point that he may face where he should have hit something but

hasn't, and the point where it is impossible for him to do anything because it is too late, it has been permanently damaged, I regard that as a rather serious detriment or void in the operator's knowledge and ability to cope with the plant, but it is, the cases we know, that you can't get anything done about it.

DR. MORAY: Well, that's, you know, and I guess a part of the research would be to do a review of things, of possible scenarios which need training, work out a way of doing it.

MR. EBERSOLE: It is hardly worthwhile to say when system A fails, start system B, but that has been the practice.

DR. MORAY: I mean in a sense what you want here, the distinction which is made in the trade becomes very influential between skill based, rule based and knowledge based behavior. Skill based behavior is highly automatic behavior. Writing a bicycle is an example. You respond to signals coming from the environment and without having to think about it at all, make the appropriate response.

Rule based behavior is essentially procedures. If the plant is in a situation, then I do this. If it is in that situation, then I do the other. And those rules may be spelled out as written procedures or they may be rules which are embodied in the head by training.

Knowledge based behavior is a situation where you look at the information and it does not match anything you have seen, does not match anything you have been trained for, then you have to start thinking what am I going to do about it?

MR. EBERSOLE: That was the case in TMI 2. They had no engineering knowledge handed to them, certainly not any procedure followed.

DR. MORAY: Right, but in fact operators do very well. You want to keep humans in there for the ability to deal with these sort of things. The question is how do you train for it it? We need research on it. We don't know the answer.

MR. EBERSOLE: I think you need to bore into the consequences of these very events and layer them out, but that's not done.

DR. MORAY: That's only the ones you can think of.

MR. EBERSOLE: You can think of some horrible things that for which currently at least somebody says well, we are not going to investigate that because--

MR. WARD: Jesse can think of more of them than the average person can!

DR. MORAY: Let me move on. Qualifications, there has been considerable amount of good work done by NRC on improving the quality of licensing examinations, and the way

those are done. We think there is still research to be done. Particularly there is need for research on the validity and reliability of the examinations. Do the examinations as they are carried out both the table top examinations and simulator examinations, do they actually tell you whether or not the person is well qualified? That's the validity problem. Reliability, are they independent of who administers them? Will you always get the same answer if the same person administers the examination the? Same student on different occasion, will you always get the same answer?

This is, there is research that has been done, good research. We are saying there is more of it needed, and it is needed fairly urgently because this is, the pool of employees is changing. There is, we are moving to a time when you may get less people come to you out of the nuclear Navy, have to take a wider pool of possible operators. Therefore, it is important to know how to do good licensing examinations.

Academic qualifications, we feel there is certainly room for research here. It is, this is the notorious problem of whether or not people should have degrees if they are operators or any of senior operators or whatever. There is a very peculiar state of affairs in the literature. We all, I think we all believe that academic--I use academic training in, the academic in quotes. What I mean is training in understanding of the fundamental mechanisms underlying the

process which you are dealing with, which you are operating with.

It seems that it must be the case that the more you understand about a process, the better you will be able to control it, the better you will be able to deal with it. In other words, knowledge must surely support skills. If one didn't believe that, certainly nobody would be suggesting the need for degrees.

There is a small amount of research that has been done on this topic in a variety of settings on a variety of problems in which people have been exposed to theoretical knowledge and tested to see whether it helps them to exercise skills. Without exception in the literature, it makes no difference at all. There is no, I know about eight or nine studies. Not one single one of them shows that adding theoretical knowledge helps the person to do the operational skill better.

Now that seems to me clearly nonsense. There must be something wrong with the research. I am not saying it has been done badly. It hasn't been done badly, but I cannot bring myself to believe those results. The fact of the matter is that in one sense it does make sense. You can read about how you t play a violin, and it won't--read as much as you like about it, doesn't mean you can play a violin, but on the other hand, another level, it seems it must be wrong. It can

not be true that teaching people fundamental understanding of the process they are controlling doesn't help them to control it if it is done correctly.

DR. REMICK: How about surgeons?

DR. MORAY: I clearly--you better know what part of the body it is you are cutting, although sometimes one sometimes wonders!

The point is, the only point we want to make is that if you look for objective evidence, the objective evidence says that theoretical knowledge doesn't help. What we feel is that, the correct response to that is to say we need research on how to ensure that theoretical knowledge does help. Clearly if you are faced with an unknown situation for which you have no procedures, the only thing you have got left is theoretical knowledge about how the plant will work, the engineering and the physics. Therefore, it must be possible somehow to learn how to transfer, get that knowledge, theoretical knowledge, to improve operational procedures, but we don't know how to do it at present.

MR. MICHELSON: Isn't it heavily dependent upon the time available for response?

DR. MORAY: Nobody knows.

MR. MICHELSON: Clearly if I have only a few seconds in which to do something, I am not going to react to all my theoretical knowledge. If an pilot also an engineer, it

wouldn't make a bit of difference.

DR. MORAY: The research shows as we have it that even if you have plenty of time, it doesn't help. For some reason or other, for some reason or other, theoretical knowledge doesn't become coupled to the cycle. People talk about the distinction between procedural knowledge and theoretical knowledge, between skill and knowledge if you like.

MR. EBERSOLE: There was a case, I think it is unique. At least I thought it was, where this physical knowledge, they did contribute to saving an aircraft because he applied power to highly mounted engine in the vertical stabilizer. He could correct an attitudinal problem.

DR. MORAY: I am not saying it doesn't happen. I am saying we don't know how to guarantee that the transfer of theoretical training to skills. Therefore, you get understandable resentment by operators who believe they are about to be told they have to go back and get a degree, and that's quite reasonable because even one of NRC's own documents looked at the actual content of the courses such people took and they are largely irrelevant to the actual--university degrees are not about controlling power plants.

We think, I think there may be the beginnings of an understanding as to what you have to do in order to get that

transfer. The point is we don't know how to do it at the moment, and therefore we need research on it. That's why this is an urgent problem.

MR. EBERSOLE: Internal bias in those programs, the operators being so trained really never did want to learn that stuff and never did pass legitimate examinationa on competence in the technical aspect.

DR. MORAY: I don't see why one should assume bad faith on the part of people who are complaining about how they are treated. I would prefer to assume good faith.

MR. EBERSOLE: Valid examinations, they had acquired the technical basis.

DR. MORAY: All we know, I am saying that if NRC, for example, wants to mandate engineering degrees, they are doing so at a time when there is no research to say it is going to help.

MR. EBERSOLE: Okay.m.

DR. MORAY: And the natural thing to do would be to do the research and find out how to do it, say all right, we will mandate this kind of course and that means you have to find universities or colleges to do it. You have got to get agreement on syllabus, agreement on method, and that is--otherwise it is a waste of everybody's time, not actually making any difference.

DR. SHEWMON: In any teaching situation there is

always the problem of getting the student to recognize that they have seen that problem before in a slightly different--it is clear to the professor, and you pull your hair out. It is not clear to the student, and it is to some, and it isn't to many.

DR. MORAY: That's right. That is a criticism of how the teaching is done. That shows that you are failing to teach what you are trying to teach, and you cannot assume that it must be that all students are stupid because by and large I don't think the students are stupid. We simply don't know how to do it. That's the issue. And we need research on it.

DR. SHEWMON: Some are less stupid than others.

DR. MORAY: The fact of the matter is even with the best students, we don't now how to do it. You may actually manage to do it with the bright students. We don't know how to do it deliberately. Therefore, this is a matter we really do need research.

STA, staffing, as we know, it is, there are problems to do with how well the shift technical advisor position is working. We need research to show how to improve that particular facility in nuclear power plants.

Screening and selection of staff, we feel more research could be done. When it comes to shift schedule and vigilance, these last two, screening and selection, after shift scheduling and vigilance, that is not, that is more a

matter of searching existing knowledge and applying it, seeing how to apply it fundamentally, particularly on shift scheduling, enormous amount there, and it just needs to be applied.

So that's a case of research into how to apply existing knowledge.

DR. SHEWMON: Sir, if you had come six months earlier, there would have been somebody sitting up there near you who would have tried to get you to say that indeed aptitude testing was an essential part of the selection, especially for maintenance and such things.

Do you feel this is well established or would you care to comment?

DR. MORAY: Aptitude testing is not easy. The personality testing in general is a relatively weak technology. We think that as, again as problems begin to develop about where one is going to recruit operating and maintenance personnel for nuclear industry, work should be done on this.

There is the problems about people who are responsive to stress. You know, you are not going to be able to, I think you are not going to be able to give tests that say this is the man you want. It is an excellent person, what you are really looking for, at least in the testing and screening. You are trying to make sure that you weed out

people who are likely to be hazards, and who don't work well under stress, and there are some indications of different personality types, so forth, where you might be able to say these people are at risk. You are not, never going to be able to take a test and say this person is absolutely I will guarantee 100 percent if you hire this person and not that person, this person will never make my mistakes. This person will be excellent in every way.

DR. SHEWMON: I like the word--you used aptitude better than I did when you got into psychological testing because my impression was that this person was more or felt more strongly that this was helpful with regard to aptitude, with regard to machinery or things of that sort which you thought one could test for when he was interested in psychological testing.

DR. MORAY: Was this person qualified in the literature on testing?

DR. SHEWMON: This person was qualified by having run a plant for many years and seeing who did well and who hadn't.

DR. MORAY: Yes. I remember doing some work on selection of fighter controllers for the RAF a few years ago, and we actually developed a test that would certainly have improved their recruiting by about 10 percent, considerable financial savings, in which they were totally uninterested.

They knew how to select people. They interviewed them and they talked to them about why they wanted to be RAF officers and that selects people like yourself and it is notorious in the literature that interviews, for example, is the worst possible way of selecting anybody for anything. People who want to pass--I do not believe that personality testing is sufficiently strong to enable you to identify unique individuals who are guaranteed to fulfill the role that you want for them.

The correlations are, between the test scores and subsequent performance are statistically significant but frequently not high enough to guarantee that you have weeded out a large proportion of the variants, but only people who have studied how the tests are constructed and how the methodology works are really people who can pass judgment on whether or not it is inherently weak or strong.

DR. SHEWMON: I keep saying aptitude. You keep saying personality. Is that because you want to talk about personality testing or because you consider them the same?

DR. MORAY: No. It is because I think it is easier to test for aptitude but I am prepared to concede it is impossible to test usefully for personality under some circumstances. I don't see why I should accept the critical judgment of somebody who has spent his life in a different profession about certain aspect of my profession any more than

he should accept my judgments about his profession, you know. I wouldn't expect him to let me manage a power plant. I am not quite clear why he should expect me to let him say without understanding the methodology of testing that the test must be nonsense just because it has to do with personality.

DR. SHEWMON: He thought aptitude tests were so wonderful the NRC should require the utilities use them.

DR. MORAY: I think he overestimates aptitude tests and underestimates personality tests. I don't think either, I don't think they are either that good or that bad, and if one wants to make a decision, let's do research and find out how good they are.

MR. WYLIE: That's the recommendation?

DR. MORAY: That's the recommendation, yes, is to continue to look into whether it is possible to develop more effective tests, both for aptitude, acknowledge, for personality, which will be of use. And methodology for doing that research is personally well understood.

There was some research done a few years ago by Donnette on this, simply recommending that given the importance of making sure that you have the right kind of people running plants, it is worthwhile spending some more money on research. The answer may very well be that it doesn't work, but after that is what? If we knew the answer, we wouldn't be recommending the research.

MR. MICHELSON: One of the keys of the problem is even after you understand the testing process, you are going to have to have adequate system of measuring performance thereafter to decide whether a particular testing procedure picked good people. We don't have good performance evaluators.

DR. MORAY: The problem of validation is critical, and that is very difficult. You may have to wait several years to see the results.

MR. MICHELSON: We need some means of evaluating performance. We have, we are trying to learn to do it for nuclear plants by looking at some kind of outputs from the plant, capacity factors, but we need it on individuals. I guess it will be in one of your items.

DR. MORAY: I would like to press on. I am enjoying my conversation with you very much and find it stimulating and interesting, but I would like to be able to get through our report.

Human performance, the single most important thing here we feel is research on causal model of human error, especially the situation for unplanned elements. This brings me to the question about our attitude toward human reliability and PRA.

We--by the way, we say that we need research on measurements of performance, particularly if we are going to

go to performance oriented regulation. We really don't know what are the best measures of performance of the human operator's performance. I want to talk about this a little bit because PRA and human reliability estimates have, of course, played a very central role in research. They play a role in licensing. They play a central role in the discussions of safety.

Basically, our worry is the following. There has been many attempts--Swain and Cutland, of course, the classical one, the Thorpe technique, to estimate human reliability. There have been variants on this. There have been some more, been a whole set of these things.

What they are all doing, either what they are doing or what they are based on, at present, is expert estimates of the probability of human error because we do not have a data base for the probability of human errors, particularly for rare events. We don't have empirical collection of data which tells us how often a particular kind of error is in fact made.

Now further research using existing techniques is simply refining the technique of getting experts to give you their best guess, but that's what the estimates remain.

We would support the collection of data to get empirical estimates of human error, and that presumably means improving LERs, analoging what actually happens, and collecting data from simulators and so forth.

But if you use expert judgment to establish the numbers for human reliability, you will only know whether those numbers are correct by validating it. How do you validate it? You validate it against empirical data. If you have got the empirical data, you don't need expert judgment. So if what you want is point estimates of human error rates, what is the probability of making a particular kind of error? Then any research efforts should go into compiling data, not into further ways of getting expert judgment, because we have enough of that. We have gone as far as we can go, but one can raise a second question. Is this kind of measurement what you want?

Firstly, as Swain himself says in the NUREG 178, those numbers are highly dependent upon performance, shaping factors. For example, at two or three o'clock in the morning, circadian rhythms guarantee error rate is going to be substantially higher than the nominal error rates. Every study that has ever been investigated shows that in the mornings the error rate goes up and even when people have been on that shift for a long time and think they have adapted, he still hasn't.

As Swain points out, there are a variety of conditions under stress, for example, when you can expect the error rates to go up. All of these things mean that those numbers of typical human error rate are not reliable. Even if

they were empirical ones, they are not fixed estimates. There is no fixed number which you can take to be the characteristic error rate for a particular human error.

MR. EBERSOLE: You are talking about the time of day. What about the case of the shuttle event? And what is being done to prevent that maldecision the second time?

DR. MORAY: I don't think that was a time of day. That was a--

MR. EBERSOLE: It is another set of conditions altering the decisional process, but what is going to be done now to--

DR. MORAY: I don't know. That comes under the heading of organizational and management.

MR. EBERSOLE: I know. That's what I am mostly interested in.

MR. WARD: We are on a different topic.

DR. MORAY: I will come back to that. I want to make, the following is the point I want to make and which we believe very strongly is fundamental to this.

Even if you did have empirical estimates which says the probability of making a particular kind of error is such and such, that is not what you want to to know. That tells you that the probability that a particular thing will happen at sometime.

What you need to know in order to reduce the risk of

error and hazard is when is it going to happen? The fact that it happens one in a thousand times, however you define time, is really of no interest in preventing it. It is a signal saying if it is a high number like one in ten, it means something has got to be done about it, if it is a number like one in ten to the 6th or ten to the ten, then it means this is so low that you probably don't have to do anything about it, but the point is what you want to know, is it going to happen in the next five minutes? Because if you know when it is going to happen, then you can take steps to prevent it. If you know what it is that makes it happen, you can take steps to prevent it.

You don't get that knowledge from studying error probabilities. You get that knowledge from studying error causing mechanisms, and therefore we say that the research that is needed on error, human error, is research on the causal mechanisms of the genesis of human errors. What makes people make incorrect judgments? What makes people make incorrect perception? What makes people make incorrect actions? What is it about the situation in which they are working which produces this kind of error now rather than next week or in a different situation?

It is causality that is fundamentally the thing we need to understand, not frequency. And so we say very strongly, that enough research has been done on frequency of

errors. What we now need is major research, long-term research on causality. Now some people have begun to work on that in the last few years, and we do have an understanding of methodology and we believe that should be very strongly supported. It should be one of the major ones; going to take a long time to do it. It is basic research, and almost anything we find out in it will feed back into safety fairly directly.

DR. STEINDLER: Could I ask a question? Is there any indication that the methodology is reliable?

DR. MORAY: Of the causal--oh, yes. Yes. What is happening is that we are getting, for the microtheories, we have good theories, for example, about signal noise ratio of displays and how that is, changes the probability of error. We know, we understand the distinction between signal strengths of incoming information from the environment and changes in the decision criteria inside the person. Those can be distinguished, measured quantitatively by using, applying theory of signal detection to the human operator. We are beginning to have good experimental evidence on what are called slips, which is I know what I am intend to do but in fact I reach out to press one button, in fact I press the adjacent one--slips of action.

The most--we are beginning to understand some things about what it is that makes you make a decision for one

strategy rather than another, which goes back to the point that you raised about the, there is nothing difficult about the method. That is not quite true. But there is a good standard experimental methodology for doing these problems, and it is beginning to develop quite rapidly. Five or six years, ten years ago there was nothing. Nobody was working on it.

DR. STEINDLER: And your view is that methodology is sufficiently broadly applicable to that?

DR. MORAY: Yes.

DR. STEINDLER: It is well in hand?

DR. MORAY: Oh, yes. It is--very many people are doing it and particularly if you want to transfer laboratory situation to the field situation, one is, this is a classical case. One is going to validate a laboratory study on fairly simple systems with something like a simulator. Sooner or later you are going to take it out and do it in the field, make sure what you found works. Yes, we have gotten the methodology. It is not an extremely, it is not much different from many things that are already done. It is cyclical, simply a matter of a topic that is being researched. We can do research on perception, attention, memory, decision making. Research has been done on that for years, not in this particular context, but clearly, this is the fundamental topic in many ways. What makes this particular error occur now?

If you know the answer to that, you can do something about it. PRA doesn't tell you what to do about anything except possibly don't start the thing up in the first place. It really, we are really very strongly arguing for totally different, total shift in direction of research in the context of human error.

MR. WARD: A comment on that--the risk analysts are going to continue to be interested in error rates, whether they, you know, it is productive to continue to refine their estimates or the numbers they use in risk study or not, it is a question, but they are going to be, continue to be interested in that.

DR. MORAY: Yes.

MR. WARD: I think the point this Committee has tried to make and I have tried to make kind of ineffectively over the last two, three, four years, is that that's fine. That's a valid interest, bit it has nothing to do, it has all to do with risk analysis but it has nothing to do with human factors. It is sort of like a risk analyst is going to be, continues to be interested in failure rates of diesel emergency generators, but what we are trying to do is, is to figure out how to design diesel emergency generators, and some knowledge of error rates is interesting in that, and perhaps useful, but it is hardly a substitute for figuring out how to design it. It is just one kind of minor input, and I think

that's the, what the NRC has fallen into. It has acted as if this little narrow area of research in human error rates to service the PRA program is a substitute for a human factors program, and it is not.

DR. MORAY: Yes. Distinction really is between the management of error, of risk, management of error and the measurement of it. We are arguing we must manage it.

MR. WEISS: Is this a fair interpretation of what you just said, that if a human is involved, errors will occur? And rather than addressing error rate, whether it is high or low, we want to look at when it will occur, in our operational sequence, and what we could do to prevent it?

DR. MORAY: And why it occurs; when it occurs, why it occurs, and what we can do to prevent it. If you know where it occurs, then you can do something to prevent it.

MR. WEISS: Even if we have some evidence that the rate of occurrence is very, very low because you don't know when it will happen, you still have to address it?

DR. MORAY: You have to, yes, but the point is that you have to distinguish between, when you say the human error rate is very low, you have to be very careful what you are saying. There is abundant evidence from most other industries that the rate at which humans make errors is actually quite high, but the rate at which they recover from them is also very high.

In the short haul airline industry, there was both a simulator study done by NASA few years ago, and empirical data from a short haul European airline between Britain and Germany, both of which found that cockpit crews made errors of navigation and things like this about once every five minutes, but they found them again, and the point is if you have a slow plant, you have got to distinguish between error, humans making an error, erroneous piece of behavior, and that emerging as plant performance.

Now we are talking about human error behavior. The plant will absorb a lot of errors. The hazard only arises when the error turns into performance of the plant output. And the, some recent work in which Woods shows that for example, people are very good at detecting their own erroneous action. If they do something incorrectly, they almost always spot it. If they make an incorrect judgment or perception, they are very poor at spotting it. Very often it is spotted only when somebody else comes in.

For example, I mean the classical one, you can go back to TMI. The fixation on the problem solving, on the hypothesis was such that it required somebody who wasn't involved in the decision-making, goes back to the remark somebody made about programming as well. You can't find your own program bugs. Somebody coming in looking at it will find it very quickly.

We don't really know how frequently errors occur which are immediately corrected perhaps even before they emerge from the person. If I look at something, make a judgment about what I have seen, if I read a meter, make a judgment about what I have seen, it is incorrect, and I think now because of that, I shouldn't take the following action, and then before I take it I think wait a minute, I am wrong about that, that is not what I should do, nobody will ever see anything. Cognitive errors that stay inside the head are not measurable certainly not by Thorpe, but if we understand the psychological mechanism by which errors occur, what factors cause them to hoop, what predisposes people to make an error of judgment, then we can try to design displays and control systems, we could design hierarchy of interpersonal interaction in the control room. We could design management policy which would minimize those and try to remove the causes. This is the point of engineering practice to control error by the biofeedback system.

In engineering practice it is standard practice to control error by a feedback system. Controlling human error or human exacerbated risk should be done in the same way. You should use the numbers which you get in PRA or in error research not as facts about error, but as control signals which have to produce behavior to change the system. At the moment, PRAs, using them as facts is descriptive. We are

saying that those numbers, if anything, are control signals, require response to reduce the error.

Then as Dave said, the point about human factors research is to change the behavior, not to measure it in this case.

Organizational aspects--I am afraid we haven't left ourselves all that much time on this. Impact of regulation on management--we repeatedly heard that management finds itself spending so much time meeting regulation that it hasn't got time to manage. And again, let us give, let us ascribe good faith to management, and that we would like to see a discussion of styles of regulations.

Organizational design, whether it is true that different styles of organization and management is what is making a difference in availability and safety of plants when all else seems to be equal.

Operational decision-making, we would like to see some work on the selection and training of managers. How do you, what should be your criteria for recruiting managers? That seems to us to be just as important as what should be your criteria for recruiting operators.

We would like to see possible, we certainly would like to see research on whether it is possible to improve cooperation between the regulators and the regulated without reducing the rigors of regulation.

Now I know that is extremely tricky. It is very tricky politically but we believe that adversarial stance is not the way to produce the best performance from the system, if the adversarial stance is to be reduced to the regulations. It could take place in an atmosphere of more cooperation, one could imagine the industry seeing regulation as being something which helps them rather than something which hinders them, and we would like, there is research in other fields done on this, these sorts of topics, of how regulation, different styles of regulation, different modes of regulation.

As I said, internationally there are a wide variety of styles of regulation and it is not clear that any one of them is particularly better than the other, but it may be, it it is worth finding out if you can possibly do that.

Operational decision-making, management style performance, culture of reliability, how do you, how do you manage in order so that everybody involved in the plant sees reliability and safety as being inherently the most important thing which they are trying to do? It is abundantly clear in any industry operators are caught between knowing that they must work for safety, and knowing that they must work for productivity.

Is it possible to find out what kind of organizational design and management philosophy maximizes the concern with safety and keeps it alive and well? We do, we do

feel that we would like to see where it is possible a cooperation, and the way that, we feel that cooperation at the research level as I have indicated one or two times is probably an acceptable kind of cooperation between the regulator and the regulated.

We are not saying that all research should be done by NRC. Research should be done by the industry. Industry should be down into research. Research should be done by both sides on topics which seem to be of mutual good, and mutual desirability, and that would, all these are connected with that.

There is no doubt in our minds, and this seems to be supported worldwide, that organizational matters as much or no more so than operator behavior is a source of hazard and risk. You can either increase it or reduce it. If it is done well, it will reduce hazard, and improve productivity. If it is done badly, the best hardware and best designed plant in the world will not be run well by people who are ill managed. Therefore, it is imperative to discover more about the relation between management and performance in the nuclear industry.

I think probably maintenance, we came to feel that maintenance and organizational matters were the two, almost the two most important ones, sort of generic ones. I came into the panel, as did several of us, as hard edged

researchers, either engineers or psychologists who had been concerned with human information from seeing hard edged experimental research, and I certainly came out of the panel with a profound feeling that it was important to know much more about organizational and managerial matters, and that probably you could almost make more difference that way than you could by improving control. We feel very, very strongly that this is of the utmost importance as a research program.

NRC had, of course, begun to look at it before their program was closed down. There is a number of quite good reports in this area.

(Slide)

DR. MORAY: Finally we would like to see research on regulatory environment. Let me put them both up. We would like to see a deeper understanding of the appropriate mix of government regulation and self, and self-regulation by the industry. We would like to see research on developing an array of performance indicators to track plant performance, particularly that has to be done if you are going to go to performance based regulation, and in more detail, we would like to see NRC look at its own human factors. Its regulation should at least be well human factored, they are presented in ways that people can understand what they are being asked to do rather than ambiguous.

We would like to see research on the regulatory

impact on innovation. How can you support technological innovation, at the same time ensuring adequate regulation to make sure that it is safe?

There are models of regulation, and this has been researched in other industries as to what kind. It is worth looking at these alternative model plant performance indicators, so we are asking NRC to look at the human factors of its own operation and own products. It is after all staffed by humans, and therefore its behavior and products are likely to be influenced by human factors considerations in the same way that the industry is.

To summarize, we are encouraged by the initiative shown by NRC to develop and fund a new human factors research program if it receives strong support by NRC and industry, managed by qualified human factors specialist, at the branch level, and if it is staffed by a team of multi-disciplinary scientists. I am not saying they should all be human factors psychologists. They must be interdisciplinary, mix of engineers and behavior scientists, human factors specialists, and then the initial steps will have been taken.

Further steps should be taken by NRC and industry as necessary as they begin to see the implications of the report and as their new research program unfolds.

And thank you very mucy for your patience and listening to a rather lengthy presentation. I will be happy

to spend the remaining twenty minutes answering questions.

DR. SHEWMON: On that penultimate slide, did the question of the effectiveness and the strategy of using fines ever arise?

DR. MORAY: We didn't consider that as an explicit topic, no.

DR. SHEWMON: One of the things which has offended the sensitivities of one member who is not here today who is also not certified in your profession so you might not accept the reaction, but was that if somebody reports a fall and you then say by gum, you were wrong, we will fine you for it, this probably wasn't the best way to do it.

DR. MORAY: I think that we would support that. There has been talk, as you know, about whether or not you could use the same method that the FAA uses for self-reporting, of self-reporting of errors, whereby pilots are encouraged to report their own faults and providing they are not criminally, liable to criminal prosecution for them, providing they don't report too many, no action is taken. And the reports are sent through NASA so that the origin of the report is hidden, but then the actual reports are published.

That would be, it seems that the aerospace industry is benefiting from that. Certainly pilots think very well of that and they seem to be seeing this as a way of helping them to avoid errors.

DR. SHEWMON: I have never heard that. Could you give Ray a record of it?

DR. MORAY: Callbacks published it which has case reports. There is an NRC report on it. There were two reports written actually by NRC as to whether or not you could implement this for the nuclear industry, self-reporting.

MR. WARD: There has been an attempt to do that. What is it, VEPCO has a program that they are trying to develop.

DR. SIESS: That was internal within the company. Paul's question was--

MR. WARD: It wasn't going to be internal, was going to be through INPO I think, but the idea is that individual participants in the process, whether they are pilots or controllers or whatever, can submit anonymous reports of occurrences that are at the, that haven't affected the process. The airplane hasn't crashed or anything.

DR. SIESS: Nobody will tell NRC about it?

DR. MORAY: Only as a--they won't tell NRC where the report came from, merely what happened. Now there are problems with it.

DR. SIESS: There sure are. They will end up in court probably.

DR. MORAY: That's the issue, whether you can organize a self-reporting system analagous to the airlines.

The other thing, one seems to work very well. I think there are some reasons why it would be much harder to make it work in the nuclear industry. One reason is there aren't enough plants, that almost any report you got, a knowledgeable person could work out where it came from, whereas you can't really do that with the airlines.

MR. WARD: It seems to me Paul's question maybe was a little, started out being a little bit different, and I might rephrase it.

Is, you know, there is a question as to whether the NRC's strategy of using fines for really more serious violations is effective in reducing, making plants safer. I think the question might be is that a researchable topic? We have, all we have is opinions on it, and I don't know that there is even empirical evidence that could be sorted out one way or the other, but is that a researchable topic?

DR. MORAY: I can see some questions that could be answered. It is researchable. It is researchable. I'm not sure quite what you get out of it in the end because it is difficult to see what the control would be.

DR. SHEWMON: Not sure he can make it strong enough to convince the Commission they should change their ways.

DR. SIESS: There must have been research on rewards and punishment on effects of human behavior. We are not talking about human behavior. We are talking about

institutional behavior.

DR. MORAY: Punishment is an inefficient way of changing behavior. That's what we know about humans.

DR. SIESS: Whether rewards would help, flying the E flag?

DR. MORAY: I would say probably yes. I mean I think rewards would help.

MR. WARD: Send the resident inspector home.

DR. SIESS: Give him a little pat on the back.

DR. MORAY: I think the, one of the problems would be that in working out how it was, how that effect was working, it would be quite difficult to see at what level it was having its effect for good or bad. Is it affecting the management, the workers, soon forth? Certainly penalizing somebody who in good faith reports a problem, thinks this happened, and it was all right I caught that this time but I think this is something which is dangerous if it happens again, if you then fine him, if you punish him for doing something in good faith which he thinks is helping, that is really going to destroy it.

DR. SIESS: NRC doesn't always think it is penalizing them. It is, the fine may be $50,000 for what happened and because it is repo. in good faith they reduce it to twenty-five, so you see they have rewarded him, not penalized him.

DR. MORAY: I think it is a researchable topic, yes.

DR. MOELLER: I have found your presentation to be very good, and I also find more myself that you have certainly broadened my concept of what all the field of human factors entails.

At the very end, though, I begin to find myself with a fundamental question, and that is you have cited that of course human factors research could help a person better operate a plant say for the operator, but then you have gone on and you have told me now that human factors research, and now I am going to put words in your mouth because I know you didn't say this, but human factors research is all we need to do to tell how to better organize and staff a plant, it is all we need to do to tell how to better set up a federal agency for regulating the plant. It is all we have to do to even set up a system of performance indicators, and I guess I am just not quite ready to go that far.

I think you have very significant contribution to maybe in all of these fields, but you were commenting earlier about your professional area and so forth. I'm no management or administration specialist or anything, but I think they would challenge you that a human factors person can tell them all about how best to manage.

DR. MORAY: I don't think you heard me use the word "all" at any stage in my presentation.

DR. MOELLER: I said that. You did not. But I could jump to the conclusion that maybe you implied that.

DR. MORAY: No. What I was trying to say--oh absolutely not. Absolutely not. I mean I know that well enough. I was a harmless academic psychologist when I was rung up by the nuclear inspector who said he understood I knew all about human factors, would I brief them on the human factors of seismic inquiry? I said I don't know anything about nuclear human factors. I just happen to have been visiting somebody who does, and they said nonetheless, you know more than anyone else we can find, would you do it? And it took me four years to learn enough about the nuclear industry to feel confid making any kind of judgments. And that was spending quite a lot of time working on it.

MR. EBERSOLE: You were involved is the Sizewell inquiry?

DR. MORAY: Briefed the nuclear inspector in Brighton along with Lawrence Bainbridge. We wrote them in brief what they should look for at Sizewell inquiry in the human factors area. They adopted our brief as theirs when questioning CGB.

No. What I want to say, I mean by talking about systems, and once or twice mentioning multi-disciplinary work, what I say is absolutely fundamentally no single discipline can do this. If I was going to work on control room design,

or operating procedures, I would certainly want to, I wouldn't do it without having engineers to work with because I don't know enough about it, because if I wanted to work on anything, I would work with people who are experts in that area and what is more, I would work with the people from the industry.

DR. MOELLER: They in turn should not undertake such evaluations or studies without including human factors?

DR. MORAY: That is all I would say.

DR. MOELLER: I agree.

DR. MORAY: Certainly. The gentleman at this end of the table?

DR. STEINDLER: Yes. I would like to revisit the issue of adversarial approach. You apparently, or clarify for me what it is that you were advocating. I think one of these vugraphs showed a call for reduction in the adversarial stance. What is it that you mean by that?

DR. MORAY: I have talked to people both in the industry and in the regulatory bodies in Britain and in Canada, and in America, and I am struck by the degree of animosity in this country compared with the other countries.

For example, recently I was, we were doing some research on how to use simulators for assessment with Ontario Hydro and we found ourselves sitting in a room with some of Ontario Hydro staff, some of the people from the Atomic Energy Control Board and ourselves discussing how this should be

done. We had been using their simulator for the morning. And we were sitting around the table all saying well, the simulator is really not working very well, is it? And the Ontario Hydro people were saying no, as a matter of fact, we have never actually tried to see if we could implement this feature. The regulators were saying well, don't you think you should do that? And they were saying well, yes, we should. We really haven't had time, and I cannot imagine a conversation of that degree of amiability in which everybody in the room, the consultants, utility people, and the regulators, were sitting around jointly working in an amiable and constructive way to try to decide what to do with a situation that all three of them agreed wasn't really what it should be.

What I am saying is that that, it is not that they don't regulate rigorously. They do regulate rigorously. They just regulate rigorously in a different kind of way, and my impression is that there is so much animosity between the industry and the regulators in this country that what happens is that the industry will only go the shortest conceivable distance that it can get away with in order to satisfy regulation.

DR. STEINDLER: Let me make a comment. You have shifted from adversarial to animosity, and I think that's a very critical shift. If you were to suggest to me that the

adversarial relationship should be abandoned, then my comment is that you can't function that way. All peer review is based on the adversarial notion.

If you are suggesting that the animosity should be abandoned, then I would agree with you heartily, but I am drawing a sharp distinction between the two and that may be artificial, but it may be taken by someone who reads the vugraph that you really don't want a peer review operation where the applicant is challenged on the technical basis to demonstrate, to show case. I don't know what you want to call it. I think that has to remain.

DR. MORAY: Yes. No. That's why I keep on coming back to the thing that we would like to see positive cooperation, but it is clear that it has got to be done in areas which preserves at the same time the rigors of regulation. I tried to use the word preserving the rigor, rigorous regulation, but doing it away from the adversarial nature. That's the distinction. I think we are making the same distinction.

DR. SIESS: Were there any lawyers present at that meeting in Canada?

DR. MORAY: Any?

DR. SIESS: Lawyers present?

DR. MORAY: No. On the whole, we don't feel such a need for lawyers as you seem to down here.

DR. SIESS: Very few serious meetings between NRC and licensees that are in trouble without lawyers being present on both sides. That tells me something. I am not sure what it is.

DR. MORAY: I was struck some years ago when I first came across this by the interesting fact that in Britain, and Canada they have a parliamentary system and law has evolved on the basis of case, case studies, and the constitution is done by sort of, you know, discussions in the context of past cases.

Your constitution is a written constitution, and until very recently Canada didn't have have a written constitution. Of course the UK doesn't. It is almost as if your regulatory style a reflective of political constitution. You write the constitution, then you regulate downwards, whereas the British and Canadians have got unwritten constitution, and tell people you can do what you like providing you can show us that it is okay, and it really is. It is an interesting reflection of the political structures. It is quite striking.

DR. SHEWMON: I am not a student of this, but I feel that part of it has to do that every so often a legislater gets his name in the paper and some notoriety by accusing the industry that the regulator is in bed with the industry, and too cozy with it, and that in an effort to show that they

aren't in bed and aren't cozy, they must be more stern.

DR. MORAY: That is quite possible. We are aware of the fact even that some of the things we have suggested in the way of research about NRC on its own structure are probably strictly speaking outside its conventional mandate as to what it is allowed to do research on.

DR. SHEWMON: The legislaters in Canada don't make their points in the same way or brownie points or something I am talking about?

DR. MORAY: For some reason, there seems to be much less of that both in Canada and the UK. I should imagine in France they get positive brownie points by saying what a splendid thing nuclear energy is.

MR. WARD: On this topic of regulatory industry, I guess my prejudices are about the same as--I am not saying yours are prejudices. My prejudices are similar to your understandings. Let's put it that way.

But the contrary of what you just said, there is an interesting report, and they can get you a copy of it before you leave, that--you don't know John O'Hearn recently wrote a study he did for, I think it was, it was the Province of Ontario, provincial government, who wanted him to make an assessment of the Canadian style of regulating the nuclear power versus the U.S. style. And I think he pointed out some of the things that you have mentioned, but also he pointed out

that the Canadian style seems to be running into some problems that it is having, because of this kind of family around the table nature of regulation, there are some problems in transporting that outside of Canada, and you know, when they are interested in selling power plants to other countries, there is not a body of documented regulation. And second, maybe I found more interesting, there seems to be a problem of transporting that to another generation of people who are running and operating.

DR. MORAY: Yes. The first point you make I don't know where it is that Canada don't sell abroad, but they certainly don't sell.

The second one I think is a very interesting one, and may be valid. I think it is a widespread observation in many fields of life that the second generation of almost any organization finds it difficult to preserve the enthusiams and the dedication of the first, whether it is a political organization of a country, or whatever. I mean I think that is why Mau Tai Sung unleashed the cultural revolution was to try to keep the enthusiasm going.

I think that is, I mean I think that is interesting on all sides, and is probably independent of the particular kind of regulation. I mean we are not, remember we are not, in this document we are not getting any solutions. All we are doing is identifying questions which need to be researched.

And if I had given the impression that I know the answers, I certainly overstepped the intentions of what I meant to have been doing, got drawn into fascinating conversations with you.

What the report is about is simply areas to which we do not know the answers and where it would be nice to know them, and it occurred to me I didn't mention the absolutely paradiametric evidence where management is of importance and that is Chernobyl. Chernobyl was management-induced fault, aided by design perhaps, but basically it was a management-induced fault, and it would be extremely unwise to think that management-induced faults cannot occur in countries other than the Soviet union.

MR. EBERSOLE: By that you just don't mean in the operational context way back into the design and report decisions?

DR. MORAY: Sure. So bear in mind when you say the report, what we are doing is we are trying to give NRC our support in rebuilding a human factors program plan which is going to be difficult given its past history. Fundamentally the entire operation is driven by the fact that somewhere around about what, 30 percent, 50 percent, 80 percent, of incidents and accidents in some way human induced. As long as that remains true, it is extraordinarily difficult to see why there should not be a program of human factors research in a major industry.

MR. WARD: Neville, thank you very much. I think you have been all I hoped for.

DR. REMICK: We thank you very much--most interesting report, and we will reconvene, gentlemen, at 1:00, and we will take up operating events and incidences.

(Whereupon, at Noon, the meeting was recessed, to reconvene at 1:00 p.m. the same day.)

REPORTER'S CERTIFICATE

DOCKET NUMBER:

CASE TITLE: Advisory Committee on Reactor Safety

HEARING DATE: March 10, 1988

LOCATION: Washington, D.C.

I hereby certify that the proceedings and evidence are contained fully and accurately on the tapes and notes reported by me at the hearing in the above case before the Nuclear Regulatory Commission and that this is a true and accurate transcript of the case.

Date: March 10, 1988

Catherine L. Boyd

Official Reporter

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HUMAN FACTORS RESEARCH AND NUCLEAR SAFETY

PANEL ON HUMAN FACTORS RESEARCH NEEDS IN NUCLEAR REGULATORY RESEARCH

COMMITTEE ON HUMAN FACTORS

COMMISSION ON BEHAVIORAL AND SOCIAL SCIENCES AND EDUCATION

NATIONAL RESEARCH COUNCIL

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STANLEY DEUTSCH, Study Director (1984-1987)

BEVERLY M. HUEY, Research Associate/Consultant

THE PANEL'S CHARGE

"[to] identify study areas in the current and recent programs that may have received inadequate attention and to provide guidance to the Office of Nuclear Regulatory Research, the Nuclear Regulatory Commission (NRC), and other research and development agencies in government, private industry, and universities regarding an appropriate research program in human factors to enhance the safe operation of nuclear power plants."

TABLE 1

SUMMARY OF NRC RESEARCH

Based on list of NUREGs and NUREG/CRs provided by NRC

The following table shows the number of reports which have been published since 1975 on each topic of research. In some cases, reports have been included in more than one category because of the nature of the work.

Organization and Management	8
Training Simulators	7
Emergency Preparedness	4
Operating Procedures (including Emergency Operating Procedures)	10
Operator Errors	14
Displays and SPDSs	22
Selection	1
Job and Task Analysis	8
Allocation of Function	2
Qualifications & Licensing	23
Performance Measurement	7
Training	8
Operator Behavior, STA	9
Control Room Design Evaluation	6
Maintenance	13
Human Error Probability and PRA	27

OVERVIEW

STARTED: January 1, 1986

COMPLETED: February 29, 1988

APPROACH:

* SEVEN PANEL MEETINGS

* BRIEFINGS BY:
  - Argonne National Laboratory
  - Department of Energy
  - Electric Power Research Institute
  - Hanford Engineering Development Laboratory
  - Institute of Nuclear Power Operation
  - Nuclear Regulatory Commission
  - Westinghouse

* VISITS TO:
  - Electric Power Research Institute
  - Three Mile Island

* REVIEW OF NRC AND OTHER RELATED PUBLICATIONS

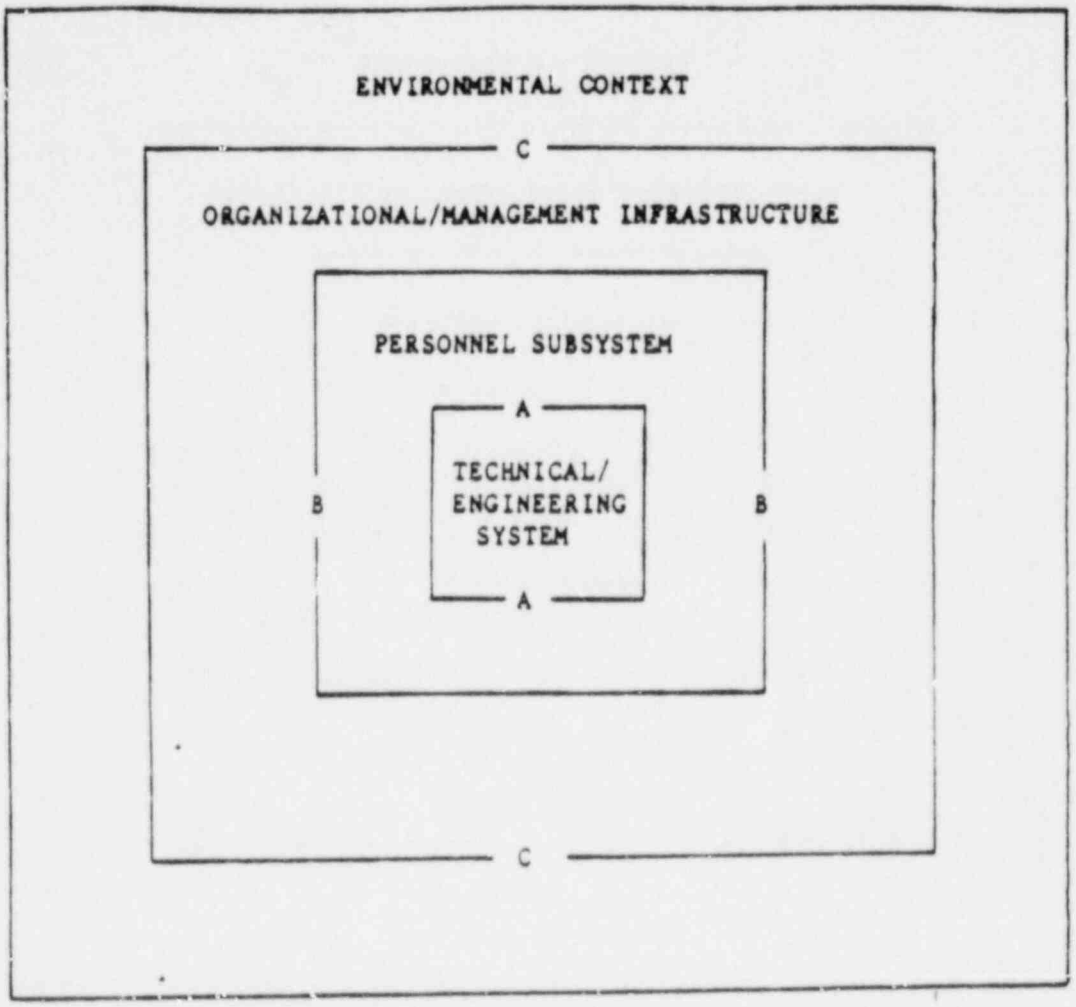

FIGURE 1

Components of a Integrative System Safety Analysis

Adapted from: Shikiar, R. An Integrative Approach To System Safety. Battelle Human Affairs Research Centers Report, BHARC 400/85/014; Seattle, Washington.

RECOMMENDATION 1: COMMITMENT TO HUMAN FACTORS RESEARCH

The panel recommends that the NRC make a firm public commitment to applied behavioral and social science (human factors safety) research. This would require a decision to increase staffing and financial support.

RECOMMENDATION 2: ADOPTING A SYSTEMS-ORIENTED APPROACH

In recognition of the many ways in which human behavior can affect nuclear power plant safety, the panel recommends that the NRC's research program maintain a broad perspective. The operator/maintainer-plant interface is extremely important; but other factors arising from the way in which a plant is organized, staffed, managed, and regulated and the way it interacts with other elements of the industry can also affect human performance, induce human error, and increase the level of risk of a plant.

RECOMMENDATION 3: PEER REVIEW AND ENHANCED ACCESS TO NUCLEAR POWER RESEARCH FACILITIES AND PERSONNEL

The panel recommends that the NRC involve a diverse group of knowledgeable researchers in planning, conducting, and evaluating its research program. In addition, peer review of proposals and of draft reports by behavioral science experts is needed to ensure the quality of sponsored research.

One of the barriers to effective human factors research has been the failure to provide behavioral science researchers access to realistic settings, to facilities such as simulators, and to people such as experienced operators. While the panel recognizes the practical difficulties involved, we strongly urge the NRC and the nuclear industry to take significant steps that enhance researchers' access to these facilities and people. One step towards achieving this goal would be to create a national research facility for the study of human factors in nuclear power systems.

RECOMMENDATION 4: CONTINUITY IN THE RESEARCH PROGRAM

For the research program to produce useful, practical results, continuity on important issues is essential. To be effective, a research program must operate coherently for an extended period rather than change in response to each new, immediate, external demand. Since effective research is cumulative, continuity is as important as level of expenditure.

RECOMMENDATION 5: TRANSFER OF KNOWLEDGE

The panel recommends that the NRC take the greatest possible advantage of existing research in the behavioral and social sciences by increasing the transfer of knowledge to the nuclear industry. To this end, the panel recommends that the NRC publish an annual review of the human factors research relevant to the nuclear power industry.

RECOMMENDATION 6: DISSEMINATION OF NUCLEAR INDUSTRY HUMAN FACTORS RESEARCH

The panel has observed that several problems exist in the usability and transfer of human factors research reports prepared by the NRC, its contractors, the national laboratories, and other elements working on human factors research related to nuclear power that should be addressed.

One impediment is the difficulty in searching for and retrieving human factors research reports. We are not aware that any central bibliographic data base or search service exists to abstract, index, and make available bibliographic or full text information, including NRC human factors publications. We recommend that mechanisms to improve the dissemination of human factors results throughout the industry be developed. One element is to use or develop a bibliographic or search service. As a first step the panel recommends the development of a bibliographic system for NRC-supported human factors reports.

RECOMMENDATION 7: A HUMAN FACTORS AGENDA

BASIS FOR DETERMINING RESEARCH PRIORITIES:

- Some research topics may have a critical impact on safety and thus must be addressed immediately.

- In some areas research is needed as a basis for evaluation.

- A particular research topic may be an essential building block for a long-term program.

NOTE: In all cases research should be aimed at management, maintenance, and other ancillary workers, as well as control room operators.

1) HUMAN-SYSTEM INTERFACE DESIGN

Highest priority topic:

- Automation and computer-based job performance aids

2) PERSONNEL SUBSYSTEM

Higher priority topics:

- Maintenance and enhancement of operational skill

- Improvements in licensing examinations

- Shift Scheduling and Vigilance

3) HUMAN PERFORMANCE

Higher priority topic:

- Causal models of human error, especially for situations with unplanned elements

4) MANAGEMENT AND ORGANIZATION

High priority topics:

- The impact of regulations on the practice of management

- Organizational design and a culture of reliability

CONTROL OF HUMAN ERROR

- In engineering it is standard practice to control error by a feedback system. Controlling human error, and hence human-induced or human-exacerbated risk, should be done in the same way. Human factors research should be seen not as an answer to a question about risk, but as a control signal in a feedback system.

- Risk analysis suggests aspects of operation that require modification because they are prone to the effects of human error. Research suggests ways to change human behavior so as to reduce human error.

- The results of these changes alter the values in the risk analysis.

- Further risk analysis and task analysis of new methods of operation will suggest further changes in operation or new candidates for sources of human-error--and the cycle will repeat.

CONTROL OF HUMAN ERROR (CONT.)

- If the results of research are to lead in a direct and practical way to the reduction of error and the reduction of risk, then research must be coupled to reliability analysis and to management, operations, maintenance, and regulation, so that an effective control signal is sent through the system.

- The NRC must conduct regulatory research on the problem of coupling the control signals of research to their reliability and risk analysis so as to optimize the control operations, not just to answer questions and accumulate knowledge.

5) THE REGULATORY ENVIRONMENT

Higher priority topics:

- The appropriate mix of government regulation and industry self-regulation

- Developing and tracking a wide array of performance indicators

Human-System Interface Design

- Computer-based information and display systems
  - Nature of effective systems
- Automation and computer-based performance aids
  - Methods of assessment and evaluation
- Operating procedures
  - Including validation
- Human factors in software development

Personnel Subsystem

- Training
  - Measurement of effectiveness
  - New methods of training
    - Whole- versus part-task simulators
    - Exploratory training
    - Embedded training
    - Rare/unknown events
- Qualifications
  - Licensing examination, validity, reliability
  - Academic qualifications
- Staffing
  - STA
  - Screening and selection
  - Shift scheduling and vigilance

Human Performance

- Measurement of performance
- Causal models of human error
  - Less emphasis on HEP estimation
  - More emphasis on predictive models

Organization Aspects of NPPS

- Impact of regulation on management
  - Style of regulations
  - Relation of production to safety
  - Regulations and cooperation
  - Reduction of adversial stance
- Organizational design
  - Management and safety
  - Management and culture of reliability
- Operational decisionmaking
  - Management style and performance
  - Emergency identification and timely response
- Selection and training of managers

Regulatory Environment

- Development of regulation
- Regulatory impact on innovation
- Human factors of NRC
- Models of regulation
- Plant performance indicators

CONCLUSIONS

The panel is encouraged by the initiative shown by the NRC to develop and fund a new human factors research program. If this plan is implemented in 1988, receives the strong support of the NRC and of the industry, is managed by a qualified human factors specialist, is staffed by a team of multidisciplinary scientists, and is organized as a separate branch rather than as a subdivision of the reliability branch, then the initial steps of leadership required of the NRC in this critical area will have been taken. Further steps will be taken as the NRC and the industry review and implement the recommendations made by the panel.