Session I

OPENING OF CONFERENCE

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CHAIRMAN: D.W. Moeller
Harvard School of Public Health

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James F. Fish

DOE WELCOME

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ON BEHALF OF THE DEPARTMENT OF ENERGY, WELCOME TO DENVER, COLORADO, THE MILE HIGH CITY, WHERE THE AIR IS THINNER, PERHAPS CRISPER BUT UNFORTUNATELY NOT CLEANER.

WE HAVE BEEN ENJOYING PERIODIC SHOWERS THROUGHOUT THE SUMMER HOWEVER YOU HAVE TIMED THIS CONFERENCE TO COINCIDE WITH EXCELLENT WEATHER CONDITIONS.

THE SURROUNDING HILLS ARE GREENER; THE MOUNTAINS BLUER AND SOME EVIDENCE OF SNOW STILL REMAINS ON THE PEAKS WEST OF THE CITY.

DENVER IS AN APPROPRIATE LOCATION FOR A NUCLEAR AIR CLEANING CONFERENCE.

WE ARE ABOUT 16 AIR MILES FROM THE DEPARTMENT OF ENERGY'S ROCKY FLATS PLANT, OPERATED BY ROCKWELL INTERNATIONAL.

PART OF OUR WORK AT THE PLANT INVOLVES CHEMICALLY PROCESSING LARGE QUANTITIES OF PLUTONIUM.

THIS INVOLVES EFFLUENT AIR-STREAM CLEANING ON A MULTIMILLION DOLLAR SCALE EVERY YEAR AT ROCKY FLATS;

A HIGH PRICE TO PAY TO GUARANTEE SUCCESS IN MEETING STRINGENT ENVIRONMENTAL AIR QUALITY STANDARDS.

WHY THE HIGH COST FOR AIR CLEANING?

OUR PLANT PROCESSING SYSTEMS ARE VERY LARGE, WHICH REQUIRES OUR EFFLUENT AIR-HANDLING SYSTEMS TO BE VERY LARGE ALSO.

THESE SYSTEMS ARE CONTINUOUSLY EXPOSED TO SIGNIFICANT CONCENTRATIONS OF PLUTONIUM AEROSOLS.

MULTIPLE BANKS OF HEPA HIGH, EFFICIENT, PARTICULATE AIR FILTERS ARE REQUIRED IN THESE SYSTEMS, AND IN SPITE OF PRE-FILTERS, SOME FILTER SYSTEMS TEND TO LOAD UP SURPRISINGLY FAST.

WE HAVE ESTABLISHED A DEDICATED WORK CREW WHOSE FULL-TIME JOB IS CHANGING HEPA FILTERS AND PERFORMING IN-PLACE FILTER TESTS.

DUE TO OUR EXTENSIVE USE OF HEPA FILTERS (6000-8000 PER YEAR), WE OPERATE ONE OF THE THREE DOE HEPA FILTER TEST FACILITIES WHICH SERVICES MAINLY OUR OWN PLANT.

HOWEVER, WE ALSO TEST FILTERS FOR OTHER DOE INSTALLATIONS, AND FOR SOME NON-DOE CUSTOMERS. IN ADDITION, WE QUANTITATIVELY TEST SEVERAL THOUSAND RESPIRATOR CANISTERS EACH MONTH; WE CAN EVALUATE HEPA FILTER PERFORMANCE FOLLOWING EXPOSURE TO HIGH HUMIDITY OR HIGH TEMPERATURES, AND WE CAN FORMULATE OR ANALYZE THE FILTERING COMPONENTS.

WITH THIS BACKGROUND I WANT TO MENTION SOME THOUGHTS ON AIR CLEANING PROBLEM AREAS STILL NEEDING SOLUTIONS.
I'LL FOCUS ON TWO GENERAL AREAS:
THE FIRST IS RELATED TO SYSTEMS DESIGN AND THE HIGH COSTS FOR AIR CLEANING.

AS I SAID, OUR CURRENT AIR CLEANING SYSTEMS ARE VERY LARGE BECAUSE THEY CONTINUOUSLY "CLEAN" AIR WHICH IS NORMALLY CLEAN TO BEGIN WITH.

THIS CLEAN AIR IS IN AREAS WHICH SURROUND GLOVE BOXES AND HOT CELLS.

BASED ON OUR SAMPLING DATA, THE AIR COULD NORMALLY BE EXHAUSTED TO THE ENVIRONMENT OR RECIRCULATED WITHOUT TREATMENT.

IT IS CONTINUOUSLY CLEANED, HOWEVER, BECAUSE THIS AIR COULD BE CONTAMINATED IF RADIOACTIVE MATERIAL WERE TO BE RELEASED FROM PRIMARY CONFINEMENT STRUCTURES.

THESE AIR VOLUMES, OFTEN INHABITED BY OPERATING PERSONNEL, ARE USUALLY QUITE LARGE AND AIR CLEANUP IS EXPENSIVE.

THESE FACILITIES WERE DESIGNED BEFORE THE AGE OF ENERGY CONSERVATION.

IT SEEMS FEASIBLE TO DESIGN NUCLEAR FACILITIES WITH REDUCED AIR VOLUMES OF PRIMARY AND SECONDARY CONFINEMENT SYSTEMS, RESULTING IN SMALLER, BETTER, AND MORE ECONOMICAL CLEANUP SYSTEMS.

THE GOAL WOULD BE TO AVOID TREATING A LARGE PERCENTAGE OF THE AIR EXHAUSTED OR RECIRCULATED FROM OPERATING AREAS DURING NORMAL OPERATIONS. THE INCENTIVE IS ENERGY CONSERVATION AND THEREFORE COST SAVINGS, WITHOUT COMPROMISING HEALTH AND SAFETY.

AN ADDITIONAL REQUIREMENT IS TO DEVELOP MORE STABLE, MORE RELIABLE RADIATION DETECTION INSTRUMENTATION AND ELECTRICAL SWITCHING MECHANISMS, SO THAT UPON DETECTION OF RADIONUCLIDE RELEASE TO AN OPERATING AREA WHICH WOULD NORMALLY NOT BE FILTERED, A SIGNAL FROM THE DETECTION SYSTEM COULD BE USED TO SWITCH FROM AN UNFILTERED TO A FILTERED MODE.
THE DETECTION AND SWITCHING MECHANISMS MUST BE EXTREMELY RELIABLE.

THIS CONCEPT IS CURRENTLY BEING CONSIDERED IN SOME OF DOE'S NEWER TRITIUM-HANDLING FACILITIES, AND IS PROPOSED FOR USE IN THE WIPP.
WHEN PERFECTED, THE SAME SCHEME COULD BE MOST USEFUL IN OTHER RADIOACTIVE MATERIALS HANDLING FACILITIES.

THE SECOND AREA OF NEED IS WITH THE AIR-CLEANING DEVICES THEMSELVES. HEPA FILTERS, WITH THEIR INHERENT STRUCTURAL WEAKNESS, SERVE AS THE ONLY EFFLUENT AIR SYSTEM BARRIER BETWEEN RADIONUCLIDE PROCESS AREA AND THE ENVIRONMENT.

THEY ARE EXPECTED TO PERFORM UNDER SEVERELY ADVERSE CONDITIONS, SUCH AS CORROSIVENESS, HIGH TEMPERATURE, HIGH HUMIDITY, HIGH DUST OR SMOKE LOADING, AND POSSIBLY HIGH-PRESSURE TRANSIENTS.

ITEMS SUCH AS MECHANICAL SCRUBBERS AND PRE-FILTERS DO NOT TOTALLY RESOLVE THE PROBLEMS, AND SOME OF THEM, LARGE SCRUBBERS FOR EXAMPLE, OFTEN CREATE MORE PROBLEMS THAN THEY SOLVE.

FILTERS LOAD UP, GET PUNCTURED, AND GET WET.

THE ADHESIVE BURNS OR DETERIORATES AND THE FILTERS MUST BE CHANGED OFTEN.

I BELIEVE AN ACCEPTABLE AIR-CLEANING DEVICE SHOULD BE STRUCTURALLY STRONG, LONG LASTING, EFFICIENT, AND SHOULD FUNCTION DURING ALL KINDS OF ADVERSE SITUATIONS.

IT SHOULD BE RESTORABLE (CLEANABLE) AND NOT DETERIORATE.

AND, OF COURSE, IT SHOULD BE COST EFFECTIVE.
I AM AWARE OF R&D ACTIVITIES IN AT LEAST ONE OF THESE AREAS (RESISTANCE TO CORROSIVITY) BUT NOT ALL OF THEM.
I'M SURE THERE ARE OTHER AREAS IN NEED OF ATTENTION.
I WILL LOOK FORWARD WITH INTEREST TO THE REPORTS OF THE NEXT AIR CLEANING CONFERENCE TO SEE WHAT PROGRESS HAS BEEN ACCOMPLISHED IN THESE AREAS.
I APPRECIATE YOUR ATTENTION, AND I HOPE THAT THIS CURRENT CONFERENCE IS PRODUCTIVE AND SUCCESSFUL.

I WAS ASKED ABOUT A TOUR OF OUR NEW PLUTONIUM FACILITY, WHICH HAS RECENTLY GONE ON LINE.
THE AIR-CLEANING PROVISIONS IN THIS NEW FACILTY ARE INTERESTING (SOME WOULD SAY AWESOME) AND OF PROBABLE GREAT INTEREST TO THIS GROUP, HOWEVER, SECURITY CONSIDERATIONS WILL NOT PERMIT ME TO AUTHORIZE A TOUR.
AS AN ALTERNATIVE, KEN FREIBERG OF ROCKWELL INTERNATIONAL HAS PUT TOGETHER A SLIDE PRESENTATION OF FACILITY CONSTRUCTION AND SYSTEMS CHECK-OUT ACTIVITIES, WHICH HE IS WILLING TO PRESENT DURING BREAKS, LUNCH, OR AFTER DAILY

SESSIONS HAVE CONCLUDED IF THERE IS ENOUGH INTEREST.

THIS IS A GOOD PRESENTATION, AND I RECOMMEND THAT YOU TAKE ADVANTAGE OF KEN'S OFFER.

WELCOME AND OBJECTIVES OF THE CONFERENCE

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I join my colleague, Dade Moeller, in welcoming you to the 17th DOE Nuclear Air Cleaning Conference on behalf of Harvard University and the DOE, joint sponsors of this meeting.

Looking back to prior Conferences, we recollect that the very first one was intended as a mini-course on the general subject of air and gas cleaning technology by the staff of the Harvard Air Cleaning Laboratory because, in truth, at that time there was no discipline identifiable as nuclear air and gas cleaning technology and there were few specialists in any sort of air and gas cleaning technology. Largely because of a continuing interest and generous funding on the part of the Atomic Energy Commission, a sizable number of scientists and engineers became specialists in nuclear air and gas cleaning technology. Segments were located at all the major installations - Savannah River, Oak Ridge, Argonne, Brookhaven, Los Alamos, Hanford - at a number of universities such as Harvard and the University of Iowa at Ames, and at research institutions such as Battelle and A.D. Little. Perhaps, this could be called the Golden Age of nuclear air and gas cleaning science. We were highly involved with major technical problems of considerable complexity - waste disposal, incineration technology, aerosol science appropriate for liquid metal cooled nuclear reactors, reprocessing technology, and construction of installations known as LOFT and FFTF - to mention only the civilian nuclear power-related activities.

The Air Cleaning Conferences regularly reported the results of these activities, both the highly theoretical and the very practical, such as how to prevent a fire in a nulcear carbon bed, and the Proceedings became a major reference source of air and gas cleaning information here and abroad. Attendance at these Conferences by nationals of countries other than United States has grown continuously, making this a major international scientific meeting sponsored by an agency of the United States Government: in fact, the only regularly scheduled series in existance exclusively concerned with nuclear air and gas cleaning.

In the beginning, the scientists from other countries came to learn United States technology but soon they began making important contributions of their own. I think we have seen a reversal of the technical flow in recent years as our colleagues in Western Europe and Asia have forged ahead on all aspects of fuel reprocessing air and gas cleaning technology while the United States has been marking time for six years (since the beginning of the previous administration) in this important area of research and engineering. I think we can all say, "Thank goodness," for the continuing efforts of our foreign colleagues in this endeavor inasmuch as the day cannot be far off when we in the United States will find that we are in desperate need of their technology.

United States research programs have been greatly reduced in recent years and their character has altered such that our major efforts are directed toward perfecting and tidying up our technological base. As valuable as refinement of current techniques may be for improving our ability to provide effective and reliable air and gas cleaning equipment, this sort of utile activity provides few new or

innovative concepts that make it possible to leap forward instead of merely creeping ahead. The former U.S. advocacy for a strong basic research effort on nuclear air and gas cleaning technology seems to have evaporated. HEPA filter damage from handling is reported to be the most prevalent damage yet no one seems to be working on new framing technologies that will avoid this loss. Instead, worker training is advocated. What is needed is engineering re-design to make it impossible, or at least unlikely, that an ordinary worker can damage a filter during shipment and handling. Similarly missing is an engineering research effort to correct personnel error faults in air and gas cleaning systems that Dr. Moeller has been talking to us about for the past six or seven years.

A well worn joke is usually presented as an ancient curse attributable to the Persians, Greeks, the Chinese, or any other group of your choice. It says, "May you live during interesting times." The implication is clear that what historians later designate as "interesting times" are certain to be mighty hard on those condemned to live through them. There can be little question that we here are in the midst of interesting nuclear energy times and have been for about a decade. Not only are we closely beset by a persistent adverse public opinion that is unable or unwilling to make a distinction between the civilian nuclear power industry and nuclear warfare, but we must suffer the funding cutbacks that result from a failure of nerve among our leaders in the face of a claque of antinuclear zealots who have founded new secular religions that generate extraordinary committment among their fervent, though unthinking, initiates. It is traditional to blame the news media for this state of affairs, and it is, indeed, difficult to have faith in our newspapers when most carry a daily astrology column as a counterpart to their generally inadequate reporting of what in other contexts is referred to as the "Age of Science".

Perhaps it will be more useful to ask why these periods of tumult and disease are referred to as "interesting times". In retrospect, they have stirred the innovators to rethink old habits and come forward with new solutions to old problems. This is a working out of Toynbee's theory of challange and response, perhaps, a theory that holds that challange and adversity bring forward the best from a civilization - or its demise when it fails to respond in productive ways.

I have the unhappy feeling that nuclear engineers and others who build, own, and operate civilian nulcear facilities tend to regard nuclear air and gas cleaning devices as unwanted and unnecessary devices that get added to their creations by force of law. When I made a statement a few years ago that nulcear air and gas cleaning systems represented the last engineering safety barrier between the reactor and the public, I was taken to task by several who insisted that the containment structure was the last barrier. Nevertheless, a reading of this Conference's program will reveal the presence of papers on the subject of vented containment and ways to decontaminate the offgases by means of air and gas cleaning technology. Surely, it is clear that here, air and gas cleaning becomes the ultimate barrier for public protection and its critical importance is unimpeachable. And surely, you and I have a clear duty to make certain that this ultimate barrier is of the utmost integrity, reliability, and efficiency. I have less concern that we might fail in this ability than I have that we will succed splendidly, technically, but fail miserably in bringing the good tidings to our fellow citizens who have less interest in these matters than we.

Returning to my original thought that these are indeed interesting times for you and me in our professional lives, as well as in our secular lives, I hope it will be abundantly evident to all of us that we must do battle on two fronts: we must accomplish the technical advancements that will enable us to tell the public

that we have provided well for their welfare - not only with an adequate margin of safety but as low as reasonably achievable (ALARA), and we must somehow convince them that they can have confidence in our demonstrated achievements.

These Nuclear Air Cleaning Conferences continue to be a vital step in the steady development of scientific and engineering knowledge, and the professional competence that is necessary for the design, construction, and maintenance of superb nuclear air and gas cleaning systems.

We are here in Denver to advance that knowledge and skill another notch. We look forward, as we wait to hear the sixty-some technical presentations this week, to at least a few giant steps forward in our joint endeavor to develop evermore perfect air and gas cleaning systems for peaceful nuclear energy applications.

Again, I welcome you to the 17th Nuclear Air Cleaning Conference. My wish is that you will have as much pleasure attending as your Program Committee experienced while assembling the program and planning the meeting.

NRC POLICY ISSUES AFFECTING ACCIDENT EVALUATION AND AIR CLEANING SYSTEMS

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I am pleased to have the opportunity to represent the Nuclear Regulatory Commission at this conference. I am told it is the 17th in a successful series of technical interchanges of information between the nuclear industry and the government. In my prepared remarks I will describe some recent developments that may result in modifications of NRC criteria for filtration systems designed for nuclear power plant accidents. As you know, the accident at TMI-2 was the impetus for these developments. I also will mention incinerators for the volume reduction of radioactive wastes at nuclear power plants, and the importance of off-gas cleanup systems for such incineration systems. At the end I will hopefully have time for some questions of your choosing just in case we didn't anticipate all of your interests.

But before I get into those specific matters, I want to talk a little bit about a more general subject that will affect the future of reactor safety regulation. The Commission is developing a policy statement on safety goals for nuclear power plant accidents. It is described in a paper published last February for public comment. (NUREG-0880, "Safety Goals for Nuclear Power Plants: A Discussion Paper".)

After the accident at TMI-2 in March of 1979, the NRC responded to one of the recommendations of the Presidential Commission that it was "prepared to move forward with an explicit policy statement on safety philosophy and the role of safety cost tradeoffs in the NRC safety decisions." In the fall of 1980, the NRC began work on an explicit statement of the level of protection adequate to ensure public safety. That work culminated in the publication of NUREG-0880 for public comment. Both qualitative safety goals and numerical guidelines were included in the proposed safety policy.

The first qualitative safety goal reads "Individual members of the public should be provided a level of protection from the consequences of nuclear power plant accidents such that no individual bears a significant risk to life and health".

Each of us bears a continual risk of dying as the result of an accident. At any point in time our risk of dying is a function of our age, occupation, habits, leisure activities, and other factors. This first safety goal proposes that the risk of a nuclear accident not be a significant additional contributor to our risk of accidental death. The incremental risk should be sufficiently low that we would be able to go about our daily lives without special concern if we reside or work near a nuclear power plant.

The second qualitative safety goal states that "Societal risks to life and health from nuclear power plant accidents should be as low as reasonably achievable and should be comparable to or less than the risk of generating electricity by viable competing technologies".

The goal has two elements. First, the residual risks are to be compared to risks from other means of generating electricity. The comparative part of this goal implies that the risk from nuclear power-plant accidents should be comparable to or less than risk from plants using alternative means of generating electricity. Coal is the only viable alternative technology at this time, so the risk from coal-fired plants is the standard for comparison. Second, the risks should be reduced to the extent practical, considering costs and benefits of risk reduction. This simply acknowledges that society has finite resources for improvement of the quality and safety of life and that there are relative limits to what society is willing to spend to reduce risk in one area at the expense of higher risks in another area.

In addition to the qualitative goals, the safety policy proposed by NRC also contains some numerical guidelines.

There are two guidelines that address prompt mortality risk and delayed mortality risk. These guidelines state "The risk to an individual or to the population in the vicinity of a nuclear power plant site of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed", and "The risk to an individual or to the population in the area near a nuclear power plant site of cancer fatalities that might result from reactor accidents should not exceed one tenth of one percent of the sum of cancer fatality risks resulting from all other causes".

The 0.1% ratio of the risks of nuclear plant accidents to other risks is proposed as a reflection of the qualitative goal of no individual bearing a significant additional risk. That is, we expect that 0.1% of other accident risks is low enough that people living or working near nuclear power plants would perceive no special safety or health concern because of the plant.

One of the other risk guidelines would limit the increased risk of a delayed fatality as a result of a reactor accident to one-tenth of one percent (1 in 1,000) of the cancer risk owing to other causes. In applying the numerical guideline for delayed cancers as a population guideline, it is proposed that the population at risk be defined as the people living within 50 miles of the plant site. A substantial fraction of the population exposures from accidental releases would be expected to occur within that distance. The NRC already uses a 50-mile cutoff distance in implementing the ALARA principle embodied in Appendix I to 10 CFR Part 50 for routine reactor releases. The result of this limit on the risk to the 50-mile population is that the potential increase in delayed fatalities from all reactors at a site would be no more than a small fraction of the normal variation in the expected cancer deaths from other causes.

Our intention is that the individual and societal mortality risk guidelines be applied on a per-site rather than a per-reactor basis. Thus, persons living near multiple unit sites should be at no greater risk than those living near single unit sites. This is somewhat analogous to the way EPA's Environmental Radiation Protection Standards, 40 CFR 190, operate for normal operational releases associated with the uranium fuel cycle.

The proposed safety goals also include a benefit-cost guideline which would be used to decide whether proposed safety improvements are worth their price. Incremental reductions of risk below the numerical guidelines for societal mortality risks might be required of our licensees if they cost less than $1,000 per man-rem averted. By most reckoning, the $1,000 is a prudent value. Even so, our experience with its use in implementing Appendix I to Part 50 has shown it to have had little or no impact. We don't have any experience with its use for accident risk reduction to know if that will hold true in this case also.

Finally, the proposed safety goal contains a plant performance guideline for large-scale core-melt accidents. It states: "The likelihood of a nuclear reactor accident that results in a large-scale core melt should normally be less than one in 10,000 per year of reactor operation."

The controlling feature of public risk from nuclear reactor operation is the chance of serious core damage; the probability is small but the potential consequences are large. Of course there are large uncertainties in probabilistic assessments of the risk portended by infrequent reactor accidents, and in the evaluation of their consequences. Thus, the core melt guideline is not intended to serve as a speed limit. It is more of a screening criterion with uncertainty bands for use in deciding on regulatory actions in specific cases.

The proposed safety goals and numerical guidelines are not intended to displace or deemphasize the defense-in-depth approach in regulation of reactor safety. Rather, they are intended to make the regulatory process more cohesive and to provide a more systematic policy basis for considering changes to address new issues. The nature and extent of the consideration to be given to the numerical guidelines in individual regulatory decisions would depend on the nature of the issue, the quality of the data base, and the reach and limits of analyses involved in the probabilistic calculations. The proposed numerical guidelines are intended to aid professional judgment, not to substitute a mathematical formula for it.

The uses of safety goals and numerical guidelines will be proposed by the NRC staff in a detailed implementation plan being developed for Commission approval.

Now let me turn to some specific developments at NRC that will more directly affect you. You've probably heard about the first one - we are reevaluating accident source terms. In the past, the assumptions made in our evaluation of accidents have been very conservative in several respects. We are reviewing our current practices in this area and assessing the current state of technology to support changes in our practices.

Our preliminary assessment of the technical basis for source term estimates is described in NUREG-0772, "Technical Bases for Estimating Fission Product Behavior during LWR Accidents". It was published in 1981. We expect that the results of ongoing research will permit best estimate revised source terms to be formulated in early 1983. The objective of the NRC source term research programs is to develop a data base for assessing fission product release from the fuel and fission product transport from the fuel to the environment during severe core damage and core melt accidents. The programs will provide information on: (a) the release of fission products and non-radioactive aerosols from overheated and melting fuel; (b) the chemistry of the released fission products; (c) the aerosol formation mechanisms; (d) the transport behavior of fission products and

aerosols in the reactor coolant system and in the containment; and (e) the effectiveness of engineered systems in mitigating fission product releases. For today, I will just concentrate on the effects of properly accounting for the predominant chemical form of iodine released from fuel in an accident. It appears that the predominant form would be cesium iodide rather than the very much more volatile elemental form of iodine.

You all know that our regulations require us to define a "maximum credible accident" for site analysis and engineered safety feature design. Although we have used a non-mechanistic event (no specific accident sequence), certain accident characteristics have been prescribed as follows:

1. substantial melting of the core is assumed;

2. containment integrity is assumed to be established and its leak rate maintained at a value no greater than about 0.1% per day; and

3. engineered safety features designed to mitigate the consequences of the event are assumed to function.

Our current guideline for release of radioactive material to the containment atmosphere for these analyses is that 100% of the core inventory of noble gas and 50% of the iodine is initially available for release from containment via the airborne pathway. Typically, half of that iodine is assumed to plate out very rapidly on containment analyses. It is also assumed that 91% of the iodine is present in the elemental form, 5% is particulate (i.e., sorbed on aerosols), and 4% is organic.

Both the amounts and the physical and chemical forms of radionuclides released into the containment atmosphere are significant factors affecting the design of features whose purpose is to prevent release to the atmosphere. The evidence available today suggests that a far greater portion of radioiodine in the containment atmosphere would be expected to be in the form of the highly water soluble cesium iodide. This was a subject of discussion at the 16th Air Cleaning Conference. Other forms of iodine such as organic iodide, elemental iodine, and other species are only expected to constitute a small percentage of the total iodine.

Several conclusions are likely to result from reevaluation of the current accident source terms. First, the current data base may be sufficient to support revision of the accident characteristics on an interim basis. This could be accomplished by the selection of a suitably conservative accident sequence and a best estimate analysis of the consequences of that accident sequence in lieu of the present "design basis accident" or DBA.

A second result of our source term work has shed some light on the assertion that past regulatory assumptions regarding volatile radioiodine may have resulted in a misplaced emphasis in engineered safety feature (ESF) design. A review of current designs shows that many ESFs for mitigation of postulated accident sequences within the design basis accident envelope are likely to be effective for postulated accidents substantially more severe than the DBA. However, there is

substantial variation in their effectiveness under such conditions. The containment spray, ice condenser, and suppression pool systems are considered to be very effective for a broad spectrum of accidents. There is, however, one other system for which this conclusion is not necessarily valid which I'll describe shortly.

Our third conclusion is that the methodology of the Reactor Safety Study (WASH-1400), currently used to evaluate consequences of accidents more severe than the design basis, leads to source term estimates that are generally conservative. While there is insufficient information for a revision of these source term estimates, the currently available data base does support reassessment of several conclusions arising from previous consequence evaluations. That is, we expect a less dominant role for iodine, and we have a new understanding of the importance of delayed containment failure.

Finally, our current studies reinforce the conclusion that there remain large uncertainties associated with accident source term determinations. In particular, more research is needed on effects such as thermohydraulic and thermodynamic conditions in the core region; aerosol formation and deposition in the primary system; aerosol particle size distributions; and containment failure mechanisms. The uncertainties associated with current source term estimates are expected to be reduced, however, as the core melt technology matures and as currently funded or planned research programs are completed.

I expect that in the future we will be turning to an evaluation approach which attempts to more realistically model the events and consequences of a broad spectrum of accidents. For less severe accidents, we will need to be able to estimate a range of likely filtration system effectiveness and the associated probabilities. For the most severe accidents involving loss of containment integrity, the performance of filtration systems will be moot. The uncertainties in accidents between these two extremes may be significant and are dependent upon a number of factors, including the reliability of components or systems and operator reliability in taking action to terminate an accident or to mitigate its consequences.

Our source term study in recent months has identified one accident consequence mitigation system of concern. Some large containment PWRs would use recirculation filtration systems in lieu of containment sprays to cool the atmosphere and remove fission products following an accident. These recirculation systems employ moisture separators, prefilters, HEPA filters, and charcoal adsorbers in series. If our current understanding is correct, this type of filtration system would be ineffective when contaminated by high aerosol loading in the more severe (beyond design basis) accident sequences. Calculations indicate that it would take only a few minutes to accumulate one kilogram of aerosol per filter module. That amount may be sufficient to plug such systems. Thus, the copious quantities of aerosols expected to be produced may plug the filters in a short time and render them ineffective for much of the accident. Credit could not be taken for them in accident analyses. On the other hand, if an ESF filtration system is located outside of the primary containment, our improved understanding of the severe accident source term does not alter our earlier estimates of their performance. Such filtration systems outside containment include auxiliary building filtration systems in a pressurized water reactor (PWR), the standby gas treatment system in a boiling water reactor (BWR), and control room habitability systems. These systems are intended to remove airborne radioactive

materials that result from leakage from piping systems or containment. In all likelihood the total concentration of airborne radioiodine reaching these filtration systems would be less than presently assumed because of the influence of partitioning of the large CsI particulate fraction between the liquid and gaseous phases. The distribution of the iodine chemical species would be much different from that presently assumed. The fraction of elemental iodine would be reduced and the fractions of organic and particulate iodine may be increased. There would likely be more particulate fission products but the increase may not be enough to warrant significant concern for the overall effectiveness of these systems external to containment.

A change in the accident source term assumptions would require revision of Regulatory Guide 1.52, "Design, Testing, and Maintenance Criteria for Post-Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants". This guide specifies typical environmental conditions for atmosphere cleanup systems designed to mitigate the consequences of DBAs. With a revision to the accident source terms, the filtration system design values for iodine buildup and adsorption, and airborne concentrations of elemental iodine, methyl iodide, and particulate iodine would have to be modified.

That concludes my remarks on reactor accidents, but before closing I would like to discuss another subject I know some of you are interested in. We have been getting a lot of questions about the cleanup of off-gas streams from incinerators designed to process radioactive wastes generated at nuclear power plants.

The NRC issued a policy statement on October 16, 1981, to encourage the volume reduction of low-level radioactive wastes. It was prompted by the limited amount of space presently available for disposal at low-level waste disposal sites and the uncertainty regarding the continued operation of the disposal sites. The Commission called upon all generators of low-level radioactive waste to reduce the volumes destined for disposal and to establish programs to implement volume reduction practices. The Commission encouraged licensees to first implement a system of administrative controls, such as planning of work activities, training, and management oversight, to minimize the volume of waste generated. Then, the Commission called for evaluation of advanced equipment, such as incinerators, to achieve even greater reductions in volume. The Commission also committed to take expeditious action on requests for licensing approval of volume reduction systems.

Even before the issuance of the policy statement, several nuclear power plants were considering the installation of radwaste incineration systems. In addition, a variety of incineration system designs have been proposed by equipment vendors, including both wet scrubbing and dry off-gas cleanup systems. Successful cleanup of the off-gas stream may be difficult in certain incinerator applications because of the many types of waste to be burned and the resulting differences in combustion products; e.g., some may be corrosive while others impair charcoal adsorbers. Power plant wastes to be incinerated may include spent ion exchange resins containing relatively high concentrations of radioactive material; solid wastes containing polyvinyl chlorides, rubber and other organics; and organic liquids such as waste oils. Thus, the incinerator off-gas system may be called upon to remove particulates, maintain the concentration of corrosive combustion

products to levels that are compatible with the materials of construction of the system, reduce non-radioactive pollutants to levels that will meet EPA or state and local regulations, and remove radioiodine to levels consistent with allowable limits established by the NRC.

Although the NRC presently does not have guidance specifically addressing the acceptability of radwaste incineration system design, much of the existing guidance is applicable, namely, Regulatory Guide 1.143, "Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants" and Regulatory Guide 1.140, "Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of Light Water-Cooled Nuclear Power Plants".

However, since the offgas system has been the source of a significant fraction of the operational problems encountered with incinerators to date, the Commission is requesting that test or operational results be provided to demonstrate that design value decontamination factors can be achieved under anticipated operational conditions. Because of greater use of radwaste incineration systems at nuclear power plants or other locations in the future, we will be following up on the information presented at this conference with special interest. If you think we should be doing more, drop me a line and tell me what it is and why. We are open to your suggestions and will try hard to answer your questions.

That concludes my prepared remarks. I appreciate the opportunity to meet with you today. I hope you have a productive week.

DISCUSSION

BELLAMY: A core-melt accident could lead to 13,000 deaths. If a core-melt occurs once in 10,000 reactor-years, is 13,000 deaths in 10,000 reactor years acceptable?

MATTSON: You shouldn't expect 13,000 deaths from a core-melt accident. The safety features (especially the containment system) would limit the effects so that the likely consequences of the more probable core-melt accidents are no prompt fatalities.

CHRISTIAN: In further response to Dr. Bellamy's question, the calculated risk of 1-3 deaths per reactor year from core meltdowns, using a probability of 10^{-4} per reactor year, even though perhaps overestimated, is within the range of currently accepted risks and actual deaths from power production, either nuclear or coal. We must accept the fact that some small risks will result from power production.

THOMAS, T.R.: Was the TMI incident considered a serious accident (i.e., one accident per 10,000 reactor years)? If so, there should be no further core meltdowns for at least 150 years. I am afraid that the public perception of risk would rule out future use of nuclear reactors should we have another such incident.

MATTSON: Of course statistics don't work that way, and the next severe accident could happen tomorrow, even if the probability were one in a million. The industry's job is to see that it doesn't. Clearly, another severe accident close on the heels of the first would place the future of nuclear power in serious jeopardy.

CSILLAG: Concerning the FPC area. I would like to know if there will be any future experimental programs in order to resolve the cesium iodide issue?

MATTSON: The NRC research program on severe accidents is described in a report numbered NUREG-0900,1982. It includes the accident source term research. The generation and removal mechanisms for CsI are included in that program.

MOELLER: Has the Nuclear Regulatory Commission staff considered specifying a limit on the containment failure rate as a part of their proposed quantitative safety goals?

MATTSON: The staff had proposed to do this, but the Commission has rejected the idea as a policy matter, at this time. The rejection is probably immaterial since the technical work to develop and test a containment performance goal is incomplete and probably will remain so for another year or two.

POTENTIAL AIR CLEANING PROBLEMS IN FUSION REACTORS*

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Abstract

The first generation of fusion reactors is expected to produce energy by fusion of deuterium (D) and tritium (T). This fusion reaction produces helium and a 14.1-Mev neutron as reaction products. Tritium is rare in nature and is produced for fusion reactors by reaction of the 14.1-Mev neutron with lithium in a breeding blanket surrounding the reaction chamber. This neutron may also react with materials surrounding the reaction chamber to produce radioactive isotopes in reactor structural materials, coolant streams or building atmosphere. Thus, the principal air cleaning problems involve removal of the radioactive tritium and activation products that may enter the reactor building as a result of normal operation, maintenance, or an accident. In addition, some fusion reactor designs contain toxic materials that could potentially be released as a result of a severe accident or fire and should be considered in the design of the air-cleaning system. The Department of Energy (DOE) has programs underway to identify sources of air-borne hazards from fusion reactors so that appropriate air-cleaning systems can be designed.

I. Introduction

Nuclear fusion is one of the key technologies under development for future generation of commercial power. The scientific feasibility of fusion is expected to be demonstrated in the mid-1980's, and commercial application is anticipated to begin early in the next century.

The first generation of fusion reactors will produce energy by fusion of deuterium (D) and tritium (T). This reaction produces helium and a 14.1-Mev neutron as reaction products. Deuterium is plentiful and can be economically extracted from seawater to support a fusion economy; however, tritium is rare in nature and must be produced for fusion reactors by reaction of the 14.1-Mev neutron with lithium in a breeding blanket that surrounds the reaction chamber. This high-energy neutron also reacts with materials surrounding the reactor to produce radioactive isotopes, activation products, in structural materials, coolant streams, and the reactor building atmosphere. The specific activation products produced are a function of the materials used in constructing the reactor. Release of tritium or activation products into the reactor building during operation, maintenance or an accident constitute the principal air cleaning problems for D-T burning fusion reactors.

Also, depending upon the specific reactor design certain toxic materials are used in fusion reactors. For example lead or beryllium are used in some designs as a neutron multiplier to improve

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the tritium breeding. Also, if the lithium required for tritium breeding is used in the liquid form, toxic aerosols can be produced in fires that could result from lithium spills. These toxic materials must be considered along with the radioactive isotopes in design of the fusion reactor air-cleaning system.

The Department of Energy has design studies, safety programs, and experiments planned or in progress that will identify potential fusion reactor air-borne hazards and allow development and/or design of appropriate air-cleaning systems prior to operation of commercial fusion reactors.

II. General Description of Fusion Reactors

Energy is produced when certain light nuclei are fused together. To achieve practical power production, a thermonuclear fuel with a sufficiently high density must be contained at very high temperatures long enough for fusion reactions to occur. The nuclear reactions shown in Table I are potentially useful for production of fusion energy. Table I also indicates the energy released in each fusion reaction.

Table I. Fusion reactions and energy released.

Reactions	Energy (MeV)
$D + T \rightarrow He(4) + n$	17.6
$D + D \rightarrow He(3) + n$	3.3
$\rightarrow T + p$	4.0
$D + He(3) \rightarrow He(4) + p$	18.3
$P + Li(6) \rightarrow He(3) + He(4)$	4.0

Because of the relatively high cross-section for the deuterium-tritium reaction, the first generation of fusion reactors will almost certainly use a mixture of deuterium and tritium as fuel. Although deuterium is abundant in nature and can be economically extracted from water, tritium must be produced in the reactor.

Significant safety advantages could result from burning other fuels in more advanced reactors. Fusion reactors burning pure deuterium or using the proton-lithium fuel cycle would eliminate the requirement for breeding tritium. For pure deuterium fuel in which the reaction products [T and He(3)] are utilized as fuel, the tritium inventory would be about two orders of magnitude lower than for deuterium-tritium fuels. Proton-lithium fuels offer even greater safety advantages since they reduce tritium inventories and the inventory of activation products.(1) The higher temperature required for fusion of advanced fuels will, however, require additional advances in plasma confinement and heating. Recent experimental results in plasma confinement and heating offer promise that pure deuterium fuel or other advanced fuel may eventually be developed.

Two approaches to plasma confinement are currently under development: inertial and magnetic confinement. In the inertial confinement approach, the fuel, in the form of a small pellet, is rapidly compressed to a high density and heated to thermonuclear temperature by a short burst of energy. Either intense lasers or particle beams may be used to provide this pulse of energy. In the magnetic confinement approach, a lower-density fuel at high temperature is contained as a plasma by the magnetic field while the fusion reactions occur. The two leading magnetic confinement schemes are the tokamak and magnetic mirror. Since the tokamak concept is the most advanced in development and reactor designs, most of the discussion in this paper will be based on this concept; however, the information will be applicable in principle to the other fusion approaches as well.

STARFIRE, the tokamak reactor design shown in Figure 1, is the latest in a series of conceptual tokamak designs. This design represents the trend towards more compact reactors with features to

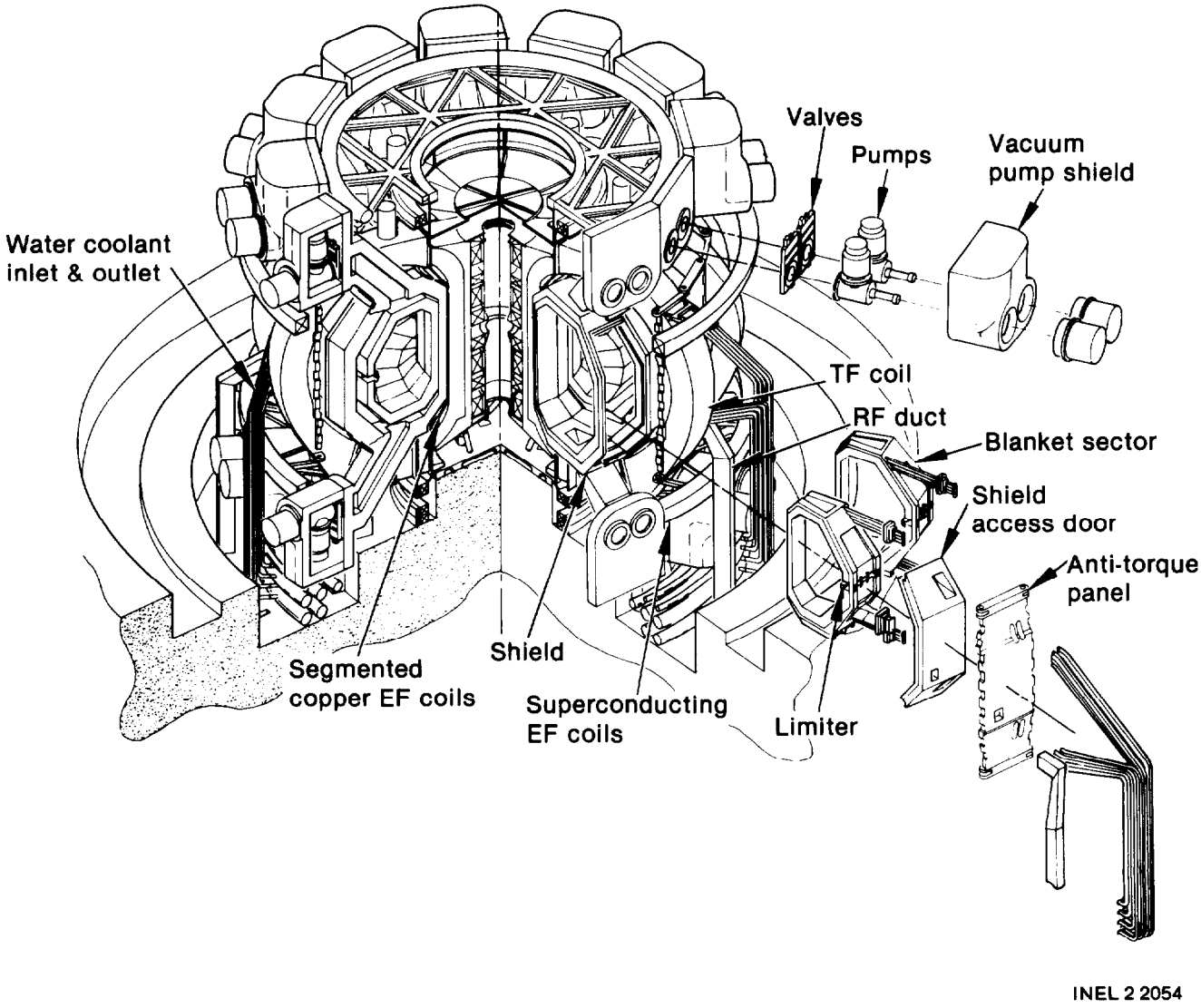

FIGURE 1
STARFIRE REFERENCE DESIGN, ISOMETRIC VIEW

facilitate maintenance and improve safety.[2] The large toroidal field (TF) coils produce magnetic fields that contain the plasma. Radio frequency (RF) waves are used to produce a current in the plasma. This current heats the plasma and produces an additional magnetic field that contributes to the plasma confinement. The RF waves also provide additional plasma heating. An austenitic stainless steel first wall is used with a beryllium coating to reduce the quantity of heavy impurities in the plasma. A pumped limiter is used to remove helium ash and other plasma impurities.

The high-energy neutrons produced in the reactions pass through the wall of the plasma chamber (first wall) and deposit their energy in the blanket. The pressurized water blanket cooling system then transfers the energy to the power generating system. The blanket also breeds additional tritium fuel through the reaction of neutrons with lithium. Lithium aluminate is used as the tritium-breeding material for STARFIRE. The primary reason for use of this ceramic compound was to eliminate the lithium fire potential and thereby improve the overall safety of the reactor. Because of the lower lithium atom density in lithium aluminate compared with liquid lithium, a neutron multiplier must be used to obtain adequate tritium breeding. Both beryllium and a lead alloy were proposed for this purpose.

The STARFIRE reactor is contained within a ribbed-box building with a volume of 2.55×10^5 m^3. The maximum accidental pressure from blowdown of the pressurized water cooling system would be approximately 100 kPa (15 psig), so the box-shaped building can be used compared with the conventional cylindrical fission reactor building. The building contains post-accident building isolation and heat removal systems. An atmospheric tritium recovery (ATR) system is provided to clean up tritium releases to the building. The system involves catalytic conversion of tritium gas to tritiated water and collection on molecular sieve. The heating, ventilating, and air conditioning systems contain high efficiency filters followed by two high efficiency particulate air (HEPA) filters.

III. Tritium Cleanup

Fusion reactors will probably contain a tritium inventory in the range from 5 to 40 kg (50 to 400 MCi).[2,3,4] Figure 2 is a simplified line diagram of a tritium system for a fusion reactor. The majority of circulating tritium will be in the fueling loop indicated by the heavy line in the figure. The largest circulating inventory will be in the vacuum pumps, the tritium processing system and the fuel fabrication injection system. In addition, reactor operation during a shutdown of the breeding system for a few weeks or the fuel processing system for a few days would require on-site storage of a few kilograms of tritium. The breeding system replenishes tritium consumed in the fusion reactor during operation. Limited data on tritium extraction from breeding materials results in large uncertainties in the equilibrium inventory in the breeding blanket. Table II lists the tritium inventories and flows for the NUWMAK and the STARFIRE conceptual designs.[2,5] The trend, indicated in this table, is towards a lower active inventory (inventory outside the breeding blanket or storage). A lower active inventory would reduce the risks associated with accidental releases.

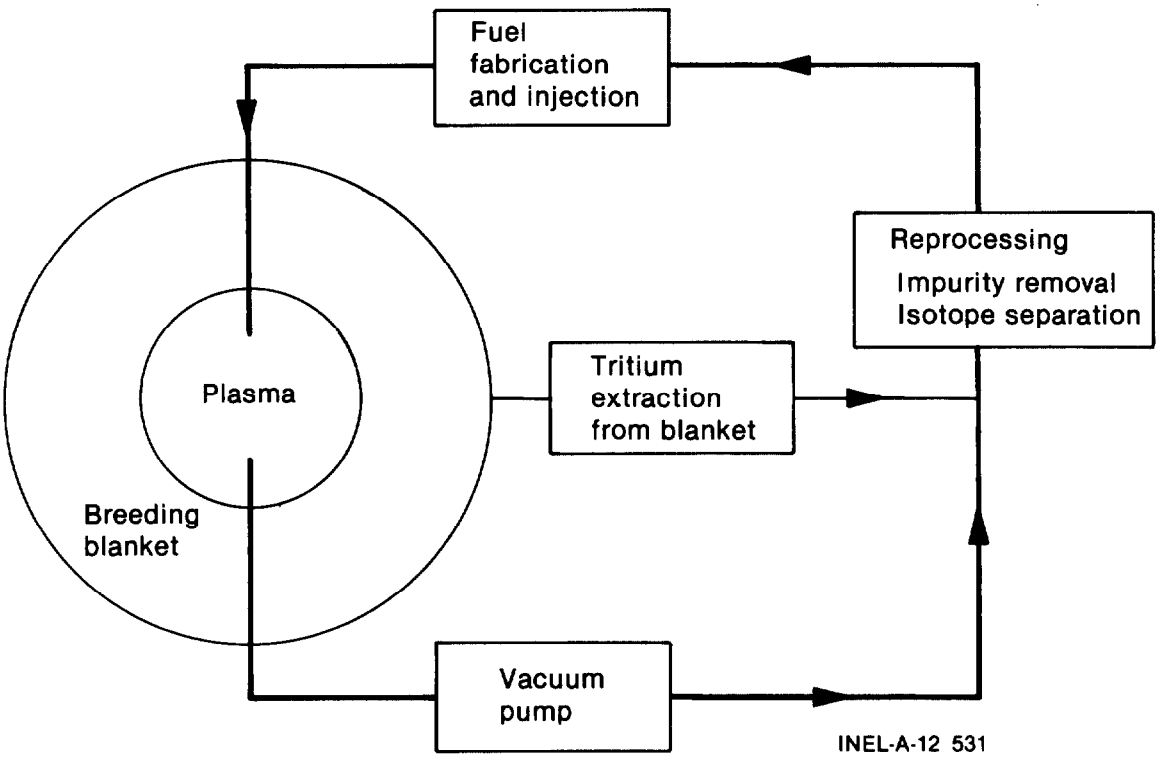

FIGURE 2
TRITIUM FUEL SYSTEM FOR A FUSION REACTOR

Table II. Tritium inventory and flows in conceptual reactor designs.

	NUWMAK	STARFIRE
Inventory (kg)		
Vacuum pumps	1.6	0.06
Reprocessing	0.35	0.15
Storage	19.4	1.1
Breeding blanket	0.1	∿10.0
Tritium recovery	---	0.28
Miscellaneous	---	0.05
Total, active	1.95	0.54
Total, blanket and storage	19.5	∿11.1
Flows (kg/day)		
Throughput	19.4	1.3
Burned	0.28	0.54

As a result of industrial and military applications, techniques for handling tritium have been developed and safety concerns are fairly well understood. Tritium decays with a half-life of 12.3 years, emitting a relatively low energy (less than 18.6 keV) beta particle. Since the penetration of the beta particle in skin is less than 0.01 mm, the primary health hazard results from inhalation and ingestion rather than external radiation. The magnitude of the hazard is dependent on the chemical form of tritium, the oxide form having a biological hazard approximately 2.5×10^4 greater than the elemental gas. Tritiated water can enter the body through the skin and lungs but is only retained in the body with a biological half-life of about 9.5 days, depending on the individual. Unlike some fission products produced in uranium or plutonium fission, tritium is not known to be concentrated in food chains.[6]

In the fusion reactor, tritium in the elemental gas form could be converted to tritiated water during an accidental release. Conversion of tritium results from the following reactions:

$$T_2 + 1/2\ O_2 \longrightarrow T_2O \qquad \text{Oxidation}$$

$$T_2 + H_2O \longrightarrow HTO + HT \qquad \text{Isotopic exchange}$$

These reactions proceed through intermediate steps involving formation of complex ions. Reaction rates are slow at room temperature and catalysis at metal surfaces or by a radiation source is required for a significant conversion rate.

Dilution of tritium gas to nonhazardous levels occurs rapidly in the atmosphere. Experience gained from accidental release of the gas indicates that even large releases may not result in serious consequences. In 1974, an accidental release of nearly 0.5 MCi of tritium gas in the elemental form occurred at the Savannah River Plant. The weather (categorized as Pasquill Type D) was neither strongly favorable nor unfavorable to local deposition. The atmospheric oxidation rate was determined to be under 1% per day, and measured atmospheric concentrations were well under calculated levels. Deposition in surface water and the levels in vegetation, milk, and biological samples did not represent a significant health hazard.[7]

During normal operation, tritium could enter the environment through leakage from gaskets and seals or by permeation through walls and pipes; leakage may be the most significant source of tritium in the primary containment. Tritium levels can be controlled by minimizing the use of gaskets and mechanical seals and by employing multiple containment techniques (double-walled piping and glove boxes) for the more sensitive components.

Accidental releases of tritium to the reactor building could occur from failure of components in the tritium fueling and processing system, the vacuum system, or the tritium breeding system. For example a failure of the breeding blanket cooling system could result in a temperature transient thereby releasing a portion of the tritium that is contained within the lithium or lithium compound breeder. Compartmentalization of systems and components can be used to reduce the quantity of tritium that is vulnerable to release during an accident. For the STARFIRE reactor design, the maximum accidental release to the building was estimated to be 10 g.[2]

In general, three different kinds of cleanup systems are envisioned to limit and control the quantity of tritium that may be released into the building; these are:

1) A coolant cleanup system to limit the buildup of tritium concentration in the primary coolant to an acceptable level.

2) Air dryers to remove tritium that enters the reactor building atmosphere from leakage during normal operation or maintenance.

3) An emergency tritium cleanup (ETC) system to clean up large accidental spills of tritium into the building.

Tritium will enter the first wall and blanket coolant streams by permeation from the plasma through the first wall, limiter, or divertor. Leakage of the coolant from seals, valves, or during maintenance will allow tritium to enter the reactor building. Thus, a system to remove the tritium from the primary coolant to limit the tritium release to the building to acceptable levels will likely be needed. For example, if the primary coolant system is water, the tritium will likely be in the oxide form and the removal could be by electrolysis and catalytic exchange. Tritium recovered by these means would likely be recycled back into the reactor fueling system.

Systems are likely to be needed to remove tritium that enters the building during normal operation to ease manned access and to reduce contamination of the building and installed components. Air dryers can be used to collect tritium in the oxide form with the resulting tritiated water stream routed through the system used to recover tritium from the primary coolant. For tritium in the isotopic gaseous form, getters such as titanium or aluminum could be used, or catalytic combination to tritium oxide could be used with the oxide form again collected by air dryers. A simplified schematic of such a system to be used at the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory is shown in Figure 3. The systems typically contain 1) a preheater to heat the tritium-containing gas to 350°C, 2) a palladium catalytic recombiner to convert tritium gas to tritium oxide, 3) an oxygen getter to remove excess oxygen, and 4) two or more molecular sieve beds to collect the tritium oxide. A capability exists to add water vapor to the process following the first molecular sieve bed to increase the efficiency of tritium collection in the second bed. Decontamination factors of 1000 are quoted for the TFTR systems.

High volume emergency tritium cleanup systems will be installed to clean up large accidental spills of tritium. These systems typically work in conjunction with the building heating, ventilating, and air conditioning (HVAC) system to remove tritium oxide. Following a large tritium spill, the reactor building is isolated and the HVAC is put into the recirculation mode. The tritium oxide is collected by condensation or moisture separators and molecular sieve beds. Conversion of the tritium to the oxide form may be accomplished either by catalytic recombination with oxygen and/or water vapor swamping.

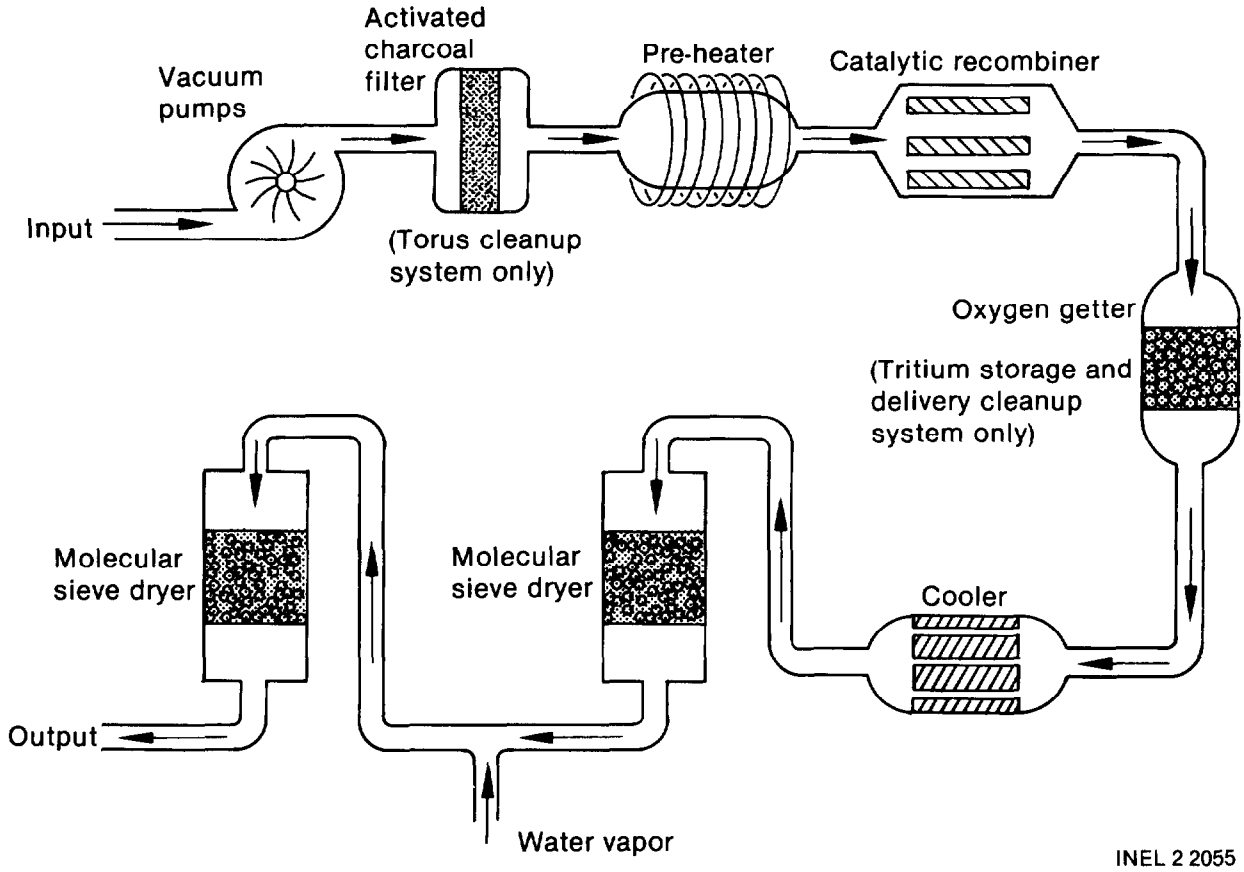

FIGURE 3
TOKAMAK FUSION TEST REACTOR (TFTR) TRITIUM CLEANUP SYSTEM

The Tritium Systems Test Assembly (TSTA) at Los Alamos National Laboratory (LANL) is the flagship of DOE's tritium handling, processing, and safety program for fusion. The facility will simulate tritium flow in a fusion reactor, excluding the breeding system, and will be used to investigate leakage and permeation problems, clean-up and containment techniques, and to develop and test components for future fusion systems. Tritium fueling system response to accident situations will be investigated to allow development of an effective safety system.[3] The TSTA will go into operation with tritium in the summer of 1982.

IV. Activation Product Cleanup Considerations

Another source of radioactivity in a fusion reactor is activation products that are generated by interaction of materials with high energy neutrons produced in the deuterium-tritium fusion reaction. The activation products are produced in structural materials, coolant streams, and reactor building gases. Calculations based on conceptual designs have shown that approximately 1 GCi of activity can be produced.[8] The large majority of these activation products are contained within the materials of the first wall, blanket,

shield, and magnet structures. Materials development programs sponsored by DOE are evaluating alloys that could achieve the high performance required and minimize the production of induced radioactivity.

Activation products are built up rapidly in the structural material of a fusion reactor and a significant fraction of the equilibrium inventory is present in the reactor after only a few days of operation. The inventory and decay characteristics of the activation products are determined by the choice of structural material. Figure 4 shows the activity and decay schemes for several structural materials being considered for fusion reactors.

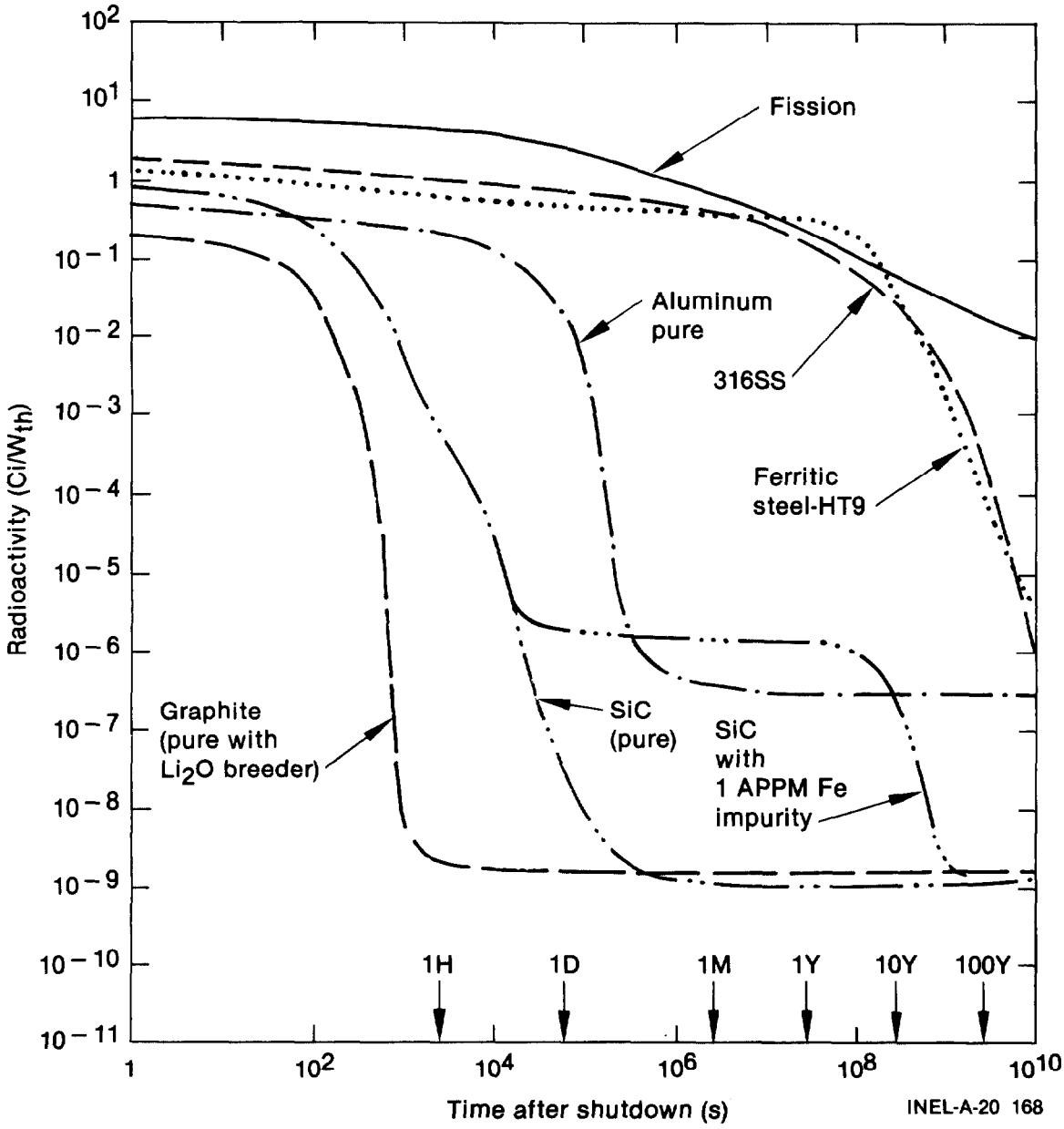

FIGURE 4
RADIOACTIVITY ASSOICATED WITH TYPICAL 3,000-MW(th) FUSION AND FISSION REACTORS AFTER TWO YEARS OF OPERATION

Stainless steel, aluminum alloys, vanadium-titanium alloy, and ferritic steel have been proposed for use as first wall and blanket materials. The extensive experience with stainless steel in fission reactors and its ease of fabrication make stainless steel an attractive candidate. However, the relatively long radioactive decay time of stainless steel complicates reactor maintenance and waste management activities. The primary activation products of concern with use of stainless steel are isotopes of iron, nickel, manganese, chromium, molybdenium, and cobalt. For STARFIRE the activation is dominated by ^{55}Fe for times up to 30 years after shutdown, by ^{63}Ni from approximately 30 to 500 years, and by ^{93}Mo for times beyond 1000 years.(2)

Ferritic steel may give a long wall life while reducing the radioactive hazard from the activation products. The effects of large neutron fluences on ferritic steels is not known, however. The rapid decay of the vanadium-titanium alloy and aluminum during the first few weeks may facilitate maintenance operations such as changing the first wall. In addition, the rapid decay for vanadium-titanium may allow early recycle of the material, however, vanadium-titanium alloy is hard to fabricate and there is limited experience in its use. Because of their low melting temperature, aluminum alloys require a lower operating temperature. Other materials, such as ceramics (e.g., SiC), may extend first wall lifetime and produce essentially no activation products. Although material choice may allow a significant reduction in the activation products, factors relating to fabrication, impurities, cost, and supply may limit the flexibility of selection.

Activation products are deposited within the coolant streams of the first wall and blanket by two primary mechanisms, sputtering caused by physical interaction of materials with high energy neutrons and corrosion. For systems with helium coolants, sputtering is the dominant mechanism. For water or liquid metal coolants, corrosion of coolant channel surfaces contributes most to the inventory. The radioactive isotopes are the same as those in the surrounding structural material. By comparison, the inventory of activation products in the coolant streams is approximately five orders of magnitude less than that contained within the solid structural materials. Analysis performed as part of the STARFIRE design showed that 3.2×10^4 Ci of radioactivity was deposited in each of the two primary coolant systems.

The primary release mechanisms for activation products from the structural material involve leakage from the primary coolant system or an energetic thermal accident. Leakage from the primary coolant could occur as a result of minor operational failures, maintenance activities or a severe coolant system accident, e.g., a pipe break. Activation products that are mobilized by such means would be expected to significantly fallout or plate out on reactor building and component surfaces. Those that remain in the reactor building atmosphere would be removed by the high efficiency and HEPA filters of the HVAC. For large releases of radioactivity from the coolant stream, the building would be isolated and the HVAC operated in the recirculation mode.

There are a number of potential thermal accidents that could be postulated to mobilize a portion of the structural activation products. These include fires, hydrogen isotope explosions, magnet system accidents, and coolant and plasma heating system failures. The most consequential of these would be lithium fires in those systems that use lithium in the more reactive forms, liquid lithium or liquid lithium-lead alloys.

Early fusion designs used liquid lithium metal for the breeding material and as a primary coolant. More recently, designs have featured less reactive lithium-lead eutectic or various solid lithium compounds. For example, the STARFIRE design has used $LiAlO_2$ as the breeding material and water as the blanket coolant. In addition, evacuated containment buildings or buildings with inert atmospheres have received consideration which would effectively eliminate lithium-air reactions.

Both experimental and analytical work are required to evaluate the trade-off between the performance achievable with liquid lithium and the potential safety advantages of less reactive lithium forms. Experimental studies[9] are underway at the Hanford Engineering Development Laboratory (HEDL) to evaluate the safety aspects of both liquid lithium and alternate lithium forms. Tests have been performed with liquid lithium to determine reaction rates and temperatures during reactions with air, argon, carbon dioxide, and concrete. Fire extinguishment techniques are also being investigated and developed. Results to date show that reaction of 100 kg of lithium with air can lead to approximately 1200 C flame temperatures. Such temperatures can cause rapid oxidization of some of the constituents of stainless steel, which could then be mobilized as aerosols. Radioisotopes of molybdenum and manganese appear susceptible to release by this mechanism. Thus, for fusion systems that use lithium in a reactive form, the air cleaning system must consider removal of activation products in the presence of lithium aerosols at high temperatures. This problem is similar to air cleaning problems in liquid metal fast breeder reactors. Tests at HEDL[9] have evaluated the effectiveness of filters and scrubbing systems for lithium fires, including various combinations of prefilters, HEPA filters, sand and gravel beds, and aqueous scrubber systems. Based on results from these tests the aqueous scrubber systems appear to offer the best combination of mass loading and filter efficiency of the various systems tested.

If lithium in a reactive form is used in fusion reactors, inherent and engineered safety design can be used to eliminate or mitigate lithium fire accidents. Based on computer modeling, the following design strategies have been shown to be effective:[10] 1) use steel liners for concrete, 2) reduce the lithium inventory per breeding loop, 3) reduce the oxygen concentration in the reactor building, 4) use structural material with high heat removal potential, 5) install a containment atmosphere cooling system, 6) employ a dump tank system below likely spill areas, and 7) employ a pressure relief ventilation system with appropriate filters.

Neutrons that stream through penetrations in the reactor shield can cause production of activation products in the building atmosphere. Reactor building atmospheres that have been considered for fusion include air, nitrogen, carbon dioxide and vacuum.

If air is used, the short-lived isotopes ^{16}N, ^{13}N, and ^{41}Ar are of primary concern. Proper shield design can limit their production to levels that can be handled by controlled release after an appropriate retention period to allow decay. The long-lived isotope ^{14}C is produced both in air and in nitrogen by the (n, p) reaction with ^{14}N. Again shield design or selective removal of the carbon by activated charcoal filtering would be relied upon to keep the quantities of this isotope to acceptable levels.

For reactors with a CO_2 environment, the primary activation product is ^{16}N formed by the (n, p) reaction with oxygen. Because of the short half life, 7.1 seconds, this isotope causes no particular problems. Some ^{14}C is also formed by neutron reaction with ^{13}C, but the quantities are well within acceptable levels. The STARFIRE reactor used a CO_2 atmosphere to reduce potential air activation problems.

V. Toxic Materials in Fusion Reactors

Fusion reactors, like most complex industrial facilities, will contain a variety of materials and compounds that are considered toxic to humans. In general the relative hazard of these toxic materials is several orders of magnitude less than that of the radioisotope hazards. Nevertheless, consideration should be given to these materials to ensure that they are properly factored into design of the air cleaning system. Probably the most significant of these toxic materials are beryllium, lead, lithium, and copper.

Beryllium may be used in fusion reactors as a neutron multiplier in the blanket, or as a coating on the first wall of the plasma chamber. As a first wall coating, the beryllium is used to limit the quantity of heavy impurities that are sputtered into the plasma. This first wall coating would be subject to erosion from the high flux of neutrons and ions to which it would be subjected. Thus, it could be expected that a significant quantity of beryllium dust could be present in the plasma chamber and vacuum system. Maintenance or a failure of these systems could result in the beryllium dust being dispersed into the reactor building.

Lead has been considered for use as either a neutron multiplier or as part of the reactor shield. In most fusion applications a severe thermal accident would be required to mobilize a significant quantity of the lead. Some designs have featured liquid lithium-lead alloys as the breeding material. These alloys do ignite and burn when exposed to air, so the lead could be dispersed into the reactor building atmosphere by the fire that could ensue from a lithium-lead spill.

As previously discussed, lithium must be used in a D-T burning fusion reactor to breed additional tritium for fuel. The various conceptual designs have featured liquid lithium, lithium-lead, and various solid ceramics such as lithium-silicate, -aluminate, or -oxide. The particular air cleaning requirements will depend on which form is used. If the liquid forms are used, the aqueous scrubber systems appear to be advantageous because of the fire potential following a spill. For the other forms, the high efficiency and HEPA filters are likely adequate.

Large quantities of copper will likely be used in magnetic confinement fusion reactors as stabilizers in the superconducting magnet system. Aluminum is an alternative to copper for this application. Typically the superconducting magnet systems will store 50 to 100 GJ of energy in the magnetic field. Should an arc develop a portion of this energy could be discharged internal to the magnet, and some of the copper could be vaporized; however, it is unlikely that significant quantities of copper could migrate beyond the coil cases or cryogenic dewar.

In general, it appears that the air cleaning systems provided for control of the tritium and activation products would suffice for air cleaning of toxic materials. However, this generality should be examined in detail for each specific fusion reactor design.

VI. Summary and Conclusions

The first generation of commercial fusion reactors will likely produce energy by the fusion of deuterium (D) and tritium (T). Based on current conceptual designs, such reactors will have a tritium inventory of approximately 10^8 Ci, and the high-energy neutrons produced in the D-T fusion process will produce on the order of 10^9 Ci of activation products in surrounding structures, coolants, and the reactor building atmosphere. Potential release of a portion of these radioactive inventories constitute the principal air cleaning problems in fusion reactors.

A multifaceted approach will be required for control of tritium. Tritium systems will employ at least double containment and triple containment where possible. Continuous tritium removal systems will be used to maintain acceptable concentrations of tritium in the reactor coolants and reactor building atmosphere. Also, high volume emergency tritium clean up systems will be employed to collect tritium from large spills. These systems operate by conversion of tritium to tritiated water by catalytic conversion and/or water vapor swamping followed by collection of the tritiated water by condensation and molecular sieve. The U.S. Department of Energy will operate the Tritium Systems Test Assembly at Los Alamos National Laboratory to develop and prove the concepts necessary for processing and control of tritium under normal and accident conditions.

The large majority of the activation products produced are metal alloying constituents of the primary structural materials. These products are bound in solid structural materials and are not readily available for release except during a severe thermal accident. Approximately 10^{-3}% of these structural activation products are deposited in the coolant streams by sputtering or corrosion. A portion of this latter inventory could be released by operational coolant leakage or by coolant system accidents such as a loss-of-coolant accident. The most likely mechanism for release of a significant quantity of activation products from the fusion reactor structural material would be a lithium fire, for those reactors that use liquid lithium or lithium-lead. Thus, one of the most significant concerns for air cleaning is the environmental conditions that accompany the release. For a loss-of-coolant accident in a fusion reactor with a pressurized water coolant, the release would be in a steam environment. Building isolation along with air cleaning by high efficiency

and HEPA filters should be adequate for this case. For releases that are caused by a lithium fire, the aqueous scrubber systems appear to offer advantages because of the high mass loadings and efficiencies obtainable. Fusion reactor designs are moving toward use of less reactive lithium compounds which should eliminate or greatly reduce the potential for release during fires.

Activation products are produced in the reactor building atmosphere by streaming of neutrons through penetrations in the reactor structure. The isotopes produced are strongly a function of the gas used in the reactor building. The quantity produced is dependent on the effectiveness of the shield design. For the most obvious choice, air, the primary isotopes produced are short-lived ^{16}N, ^{13}N, and ^{41}Ar, along with the long-lived ^{14}C. For a nitrogen atmosphere, ^{14}C is the primary product produced, and for CO_2, ^{16}N is produced. For the short-lived gases, an HVAC system design with an appropriate delay time to permit radioactive decay prior to exhaust will likely be used. Holdup tanks may be required as part of the delay system. For the ^{14}C, filtration using activated charcoal filters could be used.

Fusion reactors will potentially contain large quantities of toxic materials, including beryllium, lead, lithium, and copper. From a preliminary investigation it appears that the systems provided for removal of structural activation products could be used in the unlikely event that removal of toxic materials from the air is necessary.

In conclusion, fusion reactor design studies and technology development programs established by the DOE for fusion should allow identification and solution of air cleaning problems well before the first commercial fusion reactor is built. The solutions will draw heavily on solution to similar problems in the chemical and fission reactor industries. For the future, use of low activation materials and/or fuel cycles other than the D-T cycle would greatly reduce fusion air cleaning problems.

VII. References

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Nuclear Standards and Safety
Progress in Nuclear Standards Development

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Two years ago, when I spoke to the 16th Conference about the ASME CONAGT Committee and its assignment, I had hoped that by this time at least part of the new code would be available. Unfortunately, this is not the case. Volunteer organizations, or at least their Chairmen, tend to be over opti mistic. I now have every expectation that it will be available in part by early 1983. Certain sections for individual equipment items are complete. The overall structure has been worked out. When this is finally approved, individual equipment sections should fill in quite rapidly.

One item leading to this optimism has been a reorganization of the committee as a result of a study of the committee's work by a task group under Mel First. Their recommendations have been adopted. The effect has been to more nearly equalize the work load under seven Subcommittees.

I have the Code outline as it stands today for Engineered Safety Equipment. It will have four Divisions.

Division I will contain general requirements and common articles covering design, inspection and testing, fabrication, welding and installation, packaging and shipping, QA and nameplates and certification. Individual equipment codes will, in some cases, amplify and add particular requirements in their areas to the common section requirements.

Division II covers ventilation air cleaning and air conditioning.

DivisionIII covers process gas treatment equipment.

Division IV covers field testing to insure quality of performance.

I have every hope and expectation that substantially the whole code will be available to you by the end of 1983.

ORGANIZATION OF THE CODE ON NUCLEAR AIR AND GAS TREATMENT

GENERAL

The ASME Code on Nuclear Air and Gas Treatment consists of Divisions I through IV. All Divisions are broken down into Sections designated by two capital letters. Each Division is made up as follows:

DIVISION I - GENERAL REQUIREMENTS

Section AA - Common Articles

DIVISION II - Ventilation Air Cleaning and Ventilation Air Conditioning

Section BA - Fans and Blowers
Section DA - Dampers and Louvers
Section RA - Refrigeration Equipment
Section CB - Heating and Cooling Coils
Section CC - Humidifiers
Section CD - Electric Heaters
Section FA - Moisture Separators
Section FB - Prefilters and Frames
Section FC - HEPA Filters and Frames
Section FD - Adsorbers and Frames
Section FE - Adsorbent Media
Section IA - Instrumentation and Control
Section SA - Ductwork

DIVISION III - Process Gas Treatment

Section GA - Pressure Vessels, Piping, Heat Exchangers, and Valves
Section GB - Noble Gas Hold-Up Equipment
Section GC - Compressors
Section GD - Other Radionuclide Equipment
Section GE - Hydrogen Recombiners
Section GF - Gas Sampling

DIVISION IV - Testing Procedures

Section TA - Field Testing of Air Treatment Systems
Section TB - Field Testing of Gas Processing Systems
Section TC - Personnel Qualification
Section TD - Laboratory Qualification

CLOSING REMARKS OF SESSION CHAIRMAN:

Looking back on the opening session there has been a lot of food for thought. Even the welcoming items contained very interesting discussions. Mr. Nicks described the extensive air cleaning activities at Rocky Flats and cited what he considered to be some of our most important research news, e.g., better air cleaning systems, longer lasting systems, systems that are resistant to moisture, corrosion, and acids, etc., and finally he mentioned the need for better detectors to indicate when a given system should be brought on-line. Dr. First, in his welcome, brought out a fact many of us realize, that the US research effort in many areas is lagging behind that in foreign countries, more specifically in air cleaning research. Fortunately, foreign groups are still looking at such things as chemical processing. He also called on us to look at the real problems, not to say that simply better training of people will solve these problems. He said there are better approaches, such as to make it so that it cannot be solved improperly, or cannot be mishandled easily. Roger Mattson, in my opinion, in an excellent keynote address, reviewed, among other things, the NRC's proposed reactor safety goals. These will be qualitative and quantitative. He showed that they will definitely have an impact on air cleaning requirements in the commercial nuclear power plant area. He also pointed out that a thorough research and re-evaluation is now under way on the source term by the NRC staff. Again, the results are going to have repercussions throughout the air cleaning field. He closed with a discussion of the fact that the Nuclear Regulatory Commission has taken a position, as a policy, to encourage a reduction in the volume of low level waste at commercial plants. If this is done by using incinerators, it certainly will have an impact on the air cleaning field.

Finally, Mr. Crocker told us about fusion reactors and some of the air cleaning problems there. To me, it was rather surprising to see how far they have come with their designs in scoping the health problems that may be associated with such facilities. He also pointed out that there are tremendous energy sources within a fusion system and that these, also, must be carefully controlled. He pointed out that there will be problems associated with the tremendous quantities of tritium to be handled. In addition, there will be air cleaning problems with the induced radionuclides from high energy neutrons that result from fusion. He also pointed out that there are many other toxic materials used in fusion reactors, such as beryllium, lead, lithium, and copper. He pointed out that there is much yet to be done with respect to the air cleaning problems associated with tritium. There will be tremendous quantities and, therefore, even low leakage rates can be significant. He also pointed out that some of our present-day cleanup systems, in fact, the principal system which converts tritium from a gas to the oxide, actually increase its toxicity and this has to be looked at. He also discussed induced activity of radionuclides and stated that he thought that conventional air cleaning systems would help in this area. He also pointed out that the amount of induced activity could be modified through the selection of the structural materials used in the fusion reactor and that much attention is being given to that subject today.