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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
Thomas S. Moore, Chairman
Charles N. Kelber
Peter S. Lam

In the Matter of DUKE COGEMA STONE & WEBSTER (Savannah River Mixed Oxide Fuel Fabrication Facility)	Docket No. 0-70-03098-ML ASLBP No. 01-790-01-ML

GEORGIANS AGAINST NUCLEAR ENERGY CONTENTIONS OPPOSING A LICENSE FOR DUKE COGEMA STONE & WEBSTER TO CONSTRUCT A PLUTONIUM FUEL FACTORY AT SAVANNAH RIVER SITE

Georgians Against Nuclear Energy (GANE) is filing this amended petition to request a public hearing of safety issues concerning the proposal by Duke - COGEMA - Stone & Webster to receive a license to build a facility to manufacture reactor fuel from weapons-grade plutonium (MOX) at the Savannah River Site on the South Carolina side of the Savannah River which serves as border between Georgia and South Carolina.

Georgians' health and safety are potentially affected by hazards posed by a plutonium fuel factory on its border.

GANE observes that weapons-grade plutonium poses an inherent threat to life on earth if it is used as nuclear weapons and applauds efforts to reduce that military threat by rendering plutonium useless as a weapon.

Manufacture of plutonium fuel not only fails to reach the goal of rendering plutonium unavailable for weapons, but its manufacture and use increase the risk of

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nuclear weapons proliferation through the many transportation and handling steps in plutonium fuel manufacture.

The alternative action proposed by the U.S. Department of Energy in its plutonium disposal decision is ceramic immobilization of plutonium in which the plutonium concentration is decreased to a non-fissile level and then fixed in a ceramic form and encased in glassified high-level nuclear waste currently stored precariously in liquid form in 50-year-old tanks above the Tuscaloosa Aquifer. This lethally hot, two metric ton container, while stabilizing the high-level waste inventory at SRS, will serve as a high radiation barrier to theft of the plutonium it guards.

Since the mission of the Nuclear Regulatory Commission is to protect public health and safety, GANE observes that it is an immobilization facility which is required to protect public health from use of plutonium as weapons, not a plutonium fuel factory.

A plutonium fuel industry is unprecedented in its complexity and potential hazards. Following are several deficiencies of the MOX fuel factory Construction Authorization Request GANE has identified that threaten Georgia citizens.

GANE is filing 13 safety and environmental contentions as well as separately filing a Motion to Dismiss Licensing Proceeding or, in the Alternative, Hold It In Abeyance. We believe it is premature for the Board to consider these contentions but have filed timely to comply with the Order setting the calendar.

SAFETY CONTENTIONS

Contention 1: Lack Of Consideration Of Safeguards In Facility Design[1]

The DCS Construction Authorization Request (CAR) does not contain detailed information on MFFF design features relevant to the ability of DCS to implement material control and accounting (MC&A) measures capable of meeting or exceeding the

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[1] This contention is supported by the Declaration of Dr. Edwin S. Lyman, *see* Exhibit 1.

regulatory requirements of 10 CFR Part 74, and there is no indication that MC&A considerations were taken into account in the MFFF design. As a result, the CAR does not provide a basis for NRC to "establish that the applicant's design basis for MC&A and related commitments will lead to an FNMCP (Fundamental Nuclear Material Control Plan) that will meet or exceed the regulatory acceptance criteria in Section 13.2.4 [of the MFFF Standard Review Plan (SRP)]," SRP at 13.2.5.2A. Failure to adequately consider MP&A issues during the MFFF design phase not only exhibits poor engineering practice but also greatly increases the probability that DCS will not be able to operate the MFFF in compliance with 10 CFR Part 74 without significant retrofitting (and may not be able to even with retrofitting), and thus that NRC ultimately will deny DCS a license to possess and use SNM at the MFFF. Consequently, Chapter 13.2 of the CAR in its current form is grossly inadequate and should be rejected.

Basis: Over the last decade, the international community has recognized the importance of the principle that new nuclear facilities should be designed to facilitate the effective application of both domestic and international safeguards, and consequently that design information should be provided to safeguards authorities as early in the process as possible.

For example, as part of the series of revisions to the international safeguards regime that has occurred since the failure of IAEA safeguards to detect the Iraqi nuclear weapons program prior to the Gulf War, in February 1992 the IAEA Board of Governors adopted a widely praised recommendation that design information on new nuclear facilities should be supplied to the IAEA at least 180 days prior to commencement of construction, whereas previously it was required only that such information be provided 180 days prior to commencement of operation.[2]

The importance of this issue is summarized succinctly in a 1997 report by safeguards experts at U.S. national laboratories intended for parties interested in bidding for the MFFF contract (Erkilla et al, 1997):

> "Both domestic and international safeguards strategies must be considered when designing the MOX fuel fabrication facility. If these capabilities are not designed into the facility, it may not be possible to retrofit them into the facility and, consequently, to meet the requirements. Retrofitting safeguards into the facility may be prohibitively expensive."[3]

In other words, design of a facility without appropriate attention to safeguards issues may lead to choices that do not allow safeguards measures to be applied with a level of effectiveness adequate to meet applicable regulations. Therefore, a reasonably complete description of the safeguards approach for the facility must be submitted to the relevant safeguards authorities (in this case, NRC) at the design stage.

The MFFF SRP also makes this point clear in its guidance for the safety evaluation of construction approval of Chapter 13.2, "Material Control and Accounting" (MC&A) of the CAR, (NRC, 2000):[4]

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[2] See, for example, L. Scheinman, "Assuring the Nuclear Non-Proliferation Safeguards System," Occasional Paper Series, Atlantic Council of the United States, October 1992, p. 14.

[3] B.H. Erkilla, P.M. Rinard, K.E. Thomas and N.R. Zack (Los Alamos National Laboratory), C.D. Jaeger (Sandia National Laboratories), "Design Impacts of Safeguards and Security Requirements for a U.S. MOX Fuel Fabrication Facility," Los Alamos National Laboratory report LA-UR-97-4691, November 1997, p.4. Relevant pages are attached as Exhibit 3.

[4] U.S. NRC, Standard Review Plan for the Review of an Application for a Mixed Oxide Fuel Fabrication Facility, NUREG-1718, August 2000, Section 13.2.5.2A, p. 13.2-12.

"The primary reviewer should establish that the applicant's design basis for MC&A and related commitments will lead to an FNMCP [Fundamental Nuclear Material Control Plan] that will meet or exceed the regulatory acceptance criteria in Section 13.2.4."

The MFFF SRP defines "design basis" as[5]

"the information that identifies the specific functions to be performed by an SSC of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design."

Section 13.2 of the CAR, "Material Control and Accounting," less than one page in length, is grossly deficient and does not provide the information that NRC needs to make conclusions regarding the quality of the applicant's design basis for MC&A. The applicant merely asserts that the FNMCP it will provide when it applies for a license application for possession and use of SNM will meet the performance objectives and capabilities for the MFFF MC&A system required by 10 CFR §74.51. Other sections of the CAR refer to the location of MC&A systems but provide no "ranges of values chosen for controlling parameters" such as their performance specifications, as required by the MFFF SRP.

Since DCS has not provided any details about how MC&A considerations were integrated into the design, NRC cannot have confidence that the design of the facility will be conducive to implementation of an FNMCP that can meet its requirements. According to Erkilla et al. (1997):

[5] Ibid., p. xxii.

"Although most accounting system requirements do not have direct impact [sic] on facility design, some aspects of the accounting system, such as number and locations of measurement equipment and accounting and tracking stations, can influence floor-space requirements of the facility. ... Careful consideration should be given to the accounting system design and requirements during the facility design effort."

Erkilla, et al. also describes the exhaustive process by which this is done for DOE facilities:[6]

"At each main stage of the design process, a safeguards and security vulnerability assessment (VA) shall be performed on the facility design to determine if the design meets the intent of the DOE Orders for preventing and detecting theft or diversion of nuclear materials."

While NRC regulations do not explicitly contain a comparable requirement for conduct of VAs during the design process, the rigor of the DOE design process underscores the highly unorthodox nature of NRC's proposed MFFF licensing approach, which would allow authorization of construction of a facility without a thorough MC&A review --- a review that would require formulation of at least a preliminary FMNCP at the design stage.

A good example of how design flaws at a MOX facility can lead to a failure of the MC&A system, necessitating disruptions in operation and costly retrofits, is the Plutonium Fuel Production Facility (PFPF) in Tokaimura, Japan.[7] PFPF was described

[6] Ibid., p. 5.

[7] For a review, see E. Lyman, "Japan's Plutonium Fuel Production Facility: A Case Study of the Challenges of Nuclear Material Accountancy," Proceedings of the 38th

by the IAEA as "a highly automated facility with the most advanced material accountancy system in existence."[8] Nonetheless, during six years of operation (1988-1994), approximately 70 kilograms of plutonium accumulated on plant surfaces and process equipment, resulting in an unacceptably high value of material unaccounted for (MUF). The plant was shut down, cleaned out and retrofitted with additional systems to reduce holdup accumulation and NDA measurement uncertainty. The total cost of these operations was $100 million.

It is NRC's obligation to ensure that its regulatory process does not allow a situation like that which occurred at PFPF to develop at the MFFF. Therefore, at a minimum, the MC&A design basis must include a detailed description of how holdup accumulation (1) can be effectively managed through choices for design elements such as process equipment materials and geometries, glovebox ventilation systems and dust collection systems; and (2) can be measured with NDA systems to the degree of accuracy necessary to meet 10 CFR Part 74 requirements. It should be noted that the MFFF SRP recommends that the applicant demonstrate that the material transport system piping "is designed to minimize entrapment and buildup of solids in the system" (SRP at 11.4.7.2H), and that NRC staff have pointed out the absence of such a demonstration in the CAR (CAR RAI at 188).

In addition, the CAR does not include any information regarding the performance of the MC&A systems at the MELOX plant, which is the model for the MFFF. Such performance data, including the magnitudes of the MELOX plant MUF and "retained inventory" (process holdup that cannot be recovered until facility deactivation) could allow NRC staff to judge whether the MELOX design is compatible with MC&A

Annual Meeting of the Institute of Nuclear Materials Management, Naples, Florida, July 1998.

[8] "Japanese Nuclear Material Under Full Safeguards," press release, International Atomic Energy Agency, Vienna, May 25, 1994.

systems capable of meeting NRC regulations. It should be noted that operational data from the MELOX plant was submitted by DCS in Chapter 9 of the CAR to justify the expected values of occupational radiation exposure presented therein. By the same reasoning, MELOX MC&A performance data is likewise relevant for establishing the likelihood that the MFFF plant will be able to implement an FNMCP that can meet NRC regulations.

To illustrate the importance of MELOX operating data for establishing the adequacy of the MFFF design basis for MC&A, the example of the proposed MFFF Scrap Processing Unit (CAR at 11.2.2.10) should be considered. An effective system for management of MOX scrap is an essential component of a credible MC&A program, because MOX scrap contaminated with impurities is one of the most difficult materials in a MOX plant to measure accurately using NDA methods.[9] For this reason, NRC requirements for MOX scrap control are exceptionally stringent (10 CFR §70.58(i)(2)).

The MELOX plant has a system known as the "Unité de Chamottage" which appears to be substantially similar to the MFFF Scrap Processing Unit.[10] The throughput of this system is reported to be 8% of the MELOX plant initial licensed throughput of 101.3 MTHM of MOX per year. However, it appears that the rate of scrap production at MELOX has been much higher than anticipated and has overwhelmed its scrap processing system. There are indications that as of January 1, 2001, there were 45 MT of scrap MOX pellets from MELOX in the spent fuel storage ponds at the La Hague reprocessing plant. This implies, assuming that the MELOX scrap processing system has operated at its maximum throughput, that the average rate of scrap production at MELOX

[9] E. Lyman (1998), op cit.
[10] The information in the following paragraph was obtained from X. Coeytaux, Y. Faid and M. Schneider, "Waste Production in French MOX Fabrication Facilities," World Information Service on Energy (WISE-Paris), 10 August 2001 (attached as Exhibit 9).

for its first five years of operation has been nearly 20% of throughput, and in fact the MELOX plant is not capable of recycling the scrap it generates in a timely manner.

The description of the MFFF Scrap Processing Unit in the CAR does not provide the system design throughput. Given the scrap problems that the MELOX plant appears to be experiencing, there is reason to believe that the design and capacity of the MFFF Scrap Processing Unit, if based substantially on the MELOX system, may not be able to meet NRC requirements for scrap control. Therefore, this provides another example of the importance of design basis information for systems relevant to MC&A --- information largely omitted in the CAR --- for a determination of whether the plant design will be capable of supporting an adequate FNMCP.

The applicant asserts that because it is not required to submit an FNMCP with the CAR, "it is premature to raise contentions regarding plutonium 'accounting' at the MOX Facility."[11] However, in view of the fundamental relationship between facility design and effective MC&A documented above, it is clear that this position represents an inappropriately narrow interpretation of NRC regulations and NRC staff interpretations. This position strongly suggests that the applicant has not adequately considered MC&A issues during the design of the facility, raising the risk that DCS will not be able to submit in the future an FNMCP adequate to meet the requirements of Part 74 without costly retrofits to the MFFF. This fundamental flaw in the MFFF licensing process stems directly from the improper partitioning of the process into construction authorization and operating license phases, when in many technical areas, like MP&A, a neat division of the analysis between these two phases is not possible.

[11] DCS Answer to GANE's Request for Hearing, p. 24.

Contention 2: Lack Of Consideration Of Physical Protection In Facility Design

The DCS Construction Authorization Request (CAR) does not contain detailed information on MFFF design features relevant to the ability of DCS to implement physical protection measures capable of meeting or exceeding the regulatory requirements of 10 CFR Part 73, and there is no indication that physical protection considerations were taken into account in the MFFF design. As a result, the CAR does not provide a basis for NRC to "establish that the applicant's proposed design, location, construction technique and material for elements of the physical protection system and related commitments will lead to a physical protection plan that will meet or exceed the regulatory acceptance criteria in Section 13.1.4 [of the MFFF Standard Review Plan (SRP)]." SRP, § 13.1.5.2A.

Failure to adequately consider physical protection issues during the MFFF design phase not only exhibits poor engineering practice but also greatly increases the probability that DCS will not be able to operate the MFFF in compliance with 10 CFR Part 73 without significant retrofitting (and may not be able to even with retrofitting), and thus that NRC ultimately will deny DCS a license to possess and use SNM at the MFFF. Consequently, Chapter 13.1 of the CAR in its current form is grossly inadequate and should be rejected.

Basis: The necessity of accounting for physical protection considerations in the design of facilities that will store and use SNM is self-evident. Design elements that play a crucial role in the technical basis for physical protection include facility layout, structural design and location of physical barriers. This principle is clearly stated in the IAEA's recommendations --- representing a broad consensus among IAEA member states --- for requirements for physical protection of nuclear materials and facilities, IAEA INFCIRC/225/Rev 4:[12]

> "The concept of physical protection is one which requires a designed mixture of hardware (security devices), procedures ... and facility design (including layout)"

and

> "Achievement of the objectives of the physical protection system should be assisted by: a) Taking into account physical protection of nuclear material in the design of the facility as early as possible."

Another important reason for taking into account physical protection at the design stage is to ensure that an adequate physical protection system can be applied at the facility without compromising safety, since under certain circumstances a direct conflict arises between physical protection requirements (based on denial of access) and safety requirements (based on easy access for emergency personnel). In this regard, IAEA INFCIRC/225/Rev.4 recommends that:[13]

> "Potential conflicting requirements, resulting from safety and physical protection considerations, should be carefully analyzed to ensure that they do not jeopardize nuclear safety, including during emergency conditions."

The MFFF SRP also makes this point clear in its guidance for the safety evaluation of for construction approval of Chapter 13.1, "Material Control and Accounting" (MC&A) of the CAR:[14]

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[12] International Atomic Energy Agency, "The Physical Protection of Nuclear Materials and Facilities," INFCIRC/225/Rev. 4 (corrected), Section 6.1.1 and 6.1.2.
[13] Ibid, Section 6.1.3.
[14] U.S. NRC, NUREG-1718, Section 13.1.5.2A, p. 13.1-17.

> "The primary reviewer should establish that the applicant's proposed design, location, construction technique and material for elements of the physical protection system and related commitments will lead to a physical protection plan that will meet or exceed the regulatory acceptance criteria in Section 13.1.4."

Section 13.2 of the CAR, "Physical Security Plan," one paragraph in length, is grossly deficient and does not provide the information that NRC needs to make conclusions regarding the quality of the applicant's design basis for a physical protection system and the likelihood that it will lead to a physical protection plan that will meet NRC requirements. It merely provides a commitment that the "physical security plan" (assumed to be the same as the "physical protection plan" required by 10 CFR Part 73) that the applicant intends to file with the license application for possession and use of SNM will meet NRC requirements.

Although the CAR provides no information on how physical protection considerations were accounted for in plant design, the CAR attempts to take credit for such considerations. In particular, in addressing the possibility of damage to the MFFF from accidental explosions, the CAR states that "the impacts of explosions in F-Area are bounded by the impacts accounted for in the MFFF structures for safeguards and security reasons" (CAR at 5.5.2.7.6.2). However, this is not explained further, prompting a request from the NRC Staff to "provide the basis of the statement" at page 57 of the Staff's June 21, 2001, RAI. (The RAI is available on the NRC's MOX website). If the applicant has analysis which supports this statement, it should have provided it in the CAR.

The lack of information provided in Chapter 13.1 of the CAR suggests that the applicant has not adequately considered physical protection issues during the design of the facility, raising the risk that DCS will not be able to submit in the future a physical protection plan adequate to meet the requirements of Part 74 without costly retrofits to the MFFF. This fundamental flaw in the MFFF licensing process stems directly from the improper partitioning of the process into construction authorization and operating license phases, when in many technical areas, like physical protection, a neat division of the analysis between these two phases is not possible.

Contention 3. Inadequate Seismic Design

In Sections 1.3.5 through 1.3.7 of the CAR, DCS specifies the design criteria for the MOX Fuel Fabrication Facility to withstand any potential geological hazard. DCS claims that "conservative design criteria" have been established. *Id.* at 1.3.6-23. This assertion is not supported, because DCS has not performed a seismic analysis that is either adequate in scope or adequately documented.

Basis: The seismic hazard at a site depends on two factors: one, the likelihood of a significant seismic event, and two, the expected site response to such an event. Precisely predicting the likelihood of a future seismic event is not currently possible; the best one can do is extrapolate from past seismicity, compare regional tectonics to those of similar regions, and seek evidence for recent tectonic activity.

The site response depends upon how the local geology, soils, sediments and bedrock, would respond to an expected seismic event, the design basis earthquake. Understanding site response is a rapidly evolving field, and much is being learned as strong motion accelerographs are deployed in areas that experience earthquakes. It is essential, therefore, that any seismic study of the MFFF be complete, accurate and up-to-date.

Likelihood of significant seismic event

In Section 1.3.5, the CAR concludes that "there are no geologic threats affecting the MFFF site, except for the Charleston Seismic Zone and the minor random Piedmont earthquakes." *Id.* at 1.3.5-1. In addition, DCS states that "no conclusive evidence of large prehistoric earthquakes originating outside of coastal South Carolina have been found." CAR at p. 1.3.5-41. These assertions do not consider recent paleoseismic work on the South Carolina Coastal Plain showing more activity in the last 6000 years, and over a wider area, than previously known.

As DCS states at page 1.3-5, excavation and detailed analyses of the "liquefaction flow features" in the area of the 1886 Charleston, South Carolina earthquake provided the "first insight into the pre-history of the Charleston earthquake." On page 1.3.5-41-42 of the CAR, the applicant notes four pre-1886 liquefaction events on the coastal plain linked to Charleston events. A liquefaction episode is caused by ground shaking strong enough for soils to start to flow like a liquid. A strong enough earthquake will leave features such as sand craters, sand vents and sand fissures, as described in the application. Once located, these relict features can be dated and provide a rough timeline of pre-historic seismic events. However, the features cannot usually be used to pinpoint the earthquake location. DCS claims that paleoliquefaction episodes in areas other than the Charleston coastal plane are not addressed in the literature, and are also unlikely because of the different geology. CAR at 1.3.5-43.

Most regional paleoseismic work has only dealt with events in the Charleson Seismic Zone because liquefaction features were originally located there. A recent paper by Pradeep Talwani and William T. Schaeffer, indicates both that the frequency of major events is higher in the South Carolina Coastal Plain than previously thought, and that major events need not be limited to the Charleston seismic zone. Talwani, et al., Recurrence Rate of Large Earthquakes in the South Carolina Coastal Plain Base on

Paleoliquefaction Data, Journal of Geophysical Research, Vol. 106, April 2001, copy attached as Exhibit 5.

The Talwani/Schaeffer study includes liquefaction features along the South Carolina coast and points to two scenarios for paleoseismic activity. One scenario calls for seven magnitude seven (or stronger) Charleston events in the last 6000 years, with a recurrence interval of 600 years. The other scenario would put one magnitude six event near Bluffton, South Carolina, only 100 miles from the SRS, and the others near Charleston and Georgetown. In other words, contrary to what the CAR says, major events may have occurred much closer to the SRS than the Charleston Seismic Zone.

DCS claims to evaluate "the relationship between geologic structure and seismic sources within the general site region." However, it is impossible to evaluate the accuracy of this section because of the report's lack of references. Most tables and figures in Section 1.3.6.2 are not referenced to any published work. For those figures that do indicate the source of the information, no citation to a reference document is provided in the list of references (Section 1.3.8). *See,* for instance, Figure 1.3.6-2 (p. 1.3.6-45), Figure 1.3.6-5 (p. 1.3.6-51), and Figure 1.3.6-10 (p. 1.3.6-61). Other referenced reports are not widely available. For instance, the CAR cites a number of Westinghouse Savannah River Company technical reports that are not available through major university research libraries (e.g, The University of Colorado-Boulder or the Colorado School of Mines). Although the Westinghouse Savannah River Site web site is supposed to have reports on their website, few of the ones listed in the CAR are available. Thus, it is not possible to verify the assertions made in the CAR regarding the MFFF site geology.

Table 1.3.6-1 purports to list "Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3). No references are provided for the sources used to construct Table 1.3.6-1. Thus, they cannot be verified. Moreover, a comparison with the U.S. Geological Survey's Preliminary Determination of Epicenters, Monthly Listing, (URL: http://neic.usgs.gov/neis/epic/epic_global.html) catalog shows that it is inaccurate and incomplete at least for the period from 1974 onwards. For the August 2, 1974, event, the CAR reports a maximum magnitude of 4.3, while the USGS PDE lists a magnitude of 4.9, an energy release four times greater. Table 1 lists other catalogued events within 200 miles of the SRS of magnitude equal to or greater than 3.0 that were omitted in the CAR.

Table 1

Date (yyyy/mm/dd)	Location (Lat N)	(Lon E)	Depth (km)	Magnitude	Distance from SRS (km)
1974/10/28	33.79	-81.92		3.00 ML	66
1974/11/05	33.73	-82.22		3.70 ML	75
1979/08/26	34.93	-82.97	2	3.70 UK	223
1986/02/13	34.76	-82.94	5	3.50 Mn	205
1987/12/12	34.24	-82.63	5	3.00 Mn	143
1988/01/23	32.94	-80.16	7	3.30 Mn	145
1995/04/17	32.95	-80.07	10	3.90 Mn	153
1998/04/13	34.61	-80.47	5	3.90 Mn	190
1998/06/05	35.48	-80.82	5	3.20 Mn	262
2000/01/18	32.99	-83.21	5	3.50 Mn	144

Between the recent evidence for prehistoric earthquakes and the failure to note all recent regional seismic events, the CAR does not adequately account for the risk of a major event.

Site response

The shaking experienced at a particular location during an earthquake is called the "site response." It depends upon a number of factors, including distance to the event, regional geology and topography, and local geology and topography. The CAR cites several site response studies within the SRS, but does not indicate that a quantitative site response study for the MFFF has been done. In section 1.3.5.2, the applicant states, "Subsurface soils at the MFFF site will also be evaluated to determine whether they have any potential for liquefaction," *Id.,* p. 1.3.5-28. and, "the exploration borings, CPT holes, geophysical test results, and laboratory test results will be used to establish static and dynamic geotechnical design criteria, " *Id,* p. 1.3.5-29. Thus, the potential for intense shaking or soil liquefaction at the MFFF site has not been established.

Moreover, as noted by the NRC staff in its February 28, 2001, request for additional information (RAI) at pages 4-9, the Probabilistic Seismic Hazard Assessment (PSHA) is incomplete. (A copy of the RAI is available on the NRC's MOX website). GANE concurs with the need for clarification on all points mentioned in the RAI.

In the Standard Review Plan for Review of Final Safety Analysis Reports for Nuclear Power Plants the NRC states that license applicants should develop a site-specific design spectrum. NUREG-0800, Section 2.5.6 (1997). This means that the probability for seismic hazard, that is, the risk of a major event combined with the expected site response, should be expressed as a spectrum of the intensity of shaking at frequencies of structural interest. In the CAR, the applicant asserts that the "MFFF design earthquake is the existing SRS PC-3 spectrum." *Id.,* p. 1.3.6-23. This spectrum is not site-specific, but was computed for the whole of the Savannah River Site in 1997. A site-specific spectrum would include the soil properties determined in the geotechnical studies, such as those presented in Figures 1.3.5-23 through 1.3.5-25. The applicant has not provided detailed methodologies or references for spectral shape changes applied to the starting spectrum.

In addition, the approach to the PSHA has been insufficiently conservative. In table 1.3.6-7 (p 1.3.6-39), the applicant estimates the return period for Sa(g)=0.375g at 5hz is 2700 years. These estimates are derived from Westinghouse Savannah River Company reports (WSRC-TR-97-0085 and WSRC-TR-98-00263) that are not publicly available. In contrast, the National Seismic Hazard Mapping Project (URL:

http://geohazards.cr.usgs.gov/eq/) estimates a return period of 1200 years for the same event at the SRS.

Contention 4. Inadequate Licensing Review by NRC Staff.

The NRC lacks recent, relevant experience necessary to regulate plutonium fuel processing activities and effectively protect the public and environment from harm thereby.

Basis: It has been more than 20 years since the plutonium processing plant, Cimarron, operated near Crescent, Oklahoma. That experience resulted in early shutdown and decommissioning of the plant and a civil suit in which the licensee was found negligent with respect to worker training and safety, a finding which implicates and indicts the regulatory agency as well. Since that time, the NRC Staff has not reviewed any license applications for plutonium processing plants. The result is that the NRC Staff is embarking on a complicated licensing review for a dangerous facility, and for which it has little experience or training.

The NRC Staff's inexperience has glaringly showed itself in this licensing process (see GANE's accompanying Motion to Dismiss) in which basic and clear NRC regulations have been misinterpreted. These errors will most likely result in, at a minimum, postponing the licensing process for at least a year while DCS completes its plutonium fuel factory design. This mistake, while serious, is pale when compared to the risk posed to the public by having the NRC staff continue to grope for information on the short timeline set for it. The lack of safety- and security-related detail in the CAR, exacerbated by lack of NRC personnel with plutonium experience, coupled with a rushed licensing process could easily spell disaster for Georgians' health and property.

Correspondence between the NRC Staff and DOE shows that although it has accepted the CAR, QA Plan, and Environmental Report for docketing, the Staff is not equipped to review them without more training. The Staff is now in the process of reviewing the CAR, QA Plan, and Environmental Report, in preparation for issuance of a draft EIS and Safety Evaluation Report regarding construction. Yet, the Staff has written to the DOE, asking for "additional training of our staff in plutonium processing environments, especially with weapons-grade plutonium." *See* letter from Eric Leeds, NRC's Chief of Special Projects Branch, Division of Fuel Cycle Safety and Safeguards in the Office of Nuclear Material Safety and Safeguards to Patrick Rhoads, DOE Office of Fissile Materials Disposition, National Nuclear Security Administration (July 11, 2001), (attached as Exhibit 4). The letter also asks to procure the training services directly from Los Alamos National Laboratories, in order to cut back on the six-month lead time that the Staff anticipates if it has to go through normal channels. *Id.* Thus, the Staff seems to have embarked on a technical review for which it does not have sufficient expertise, and may not obtain training in a timely way. This lack of planning is quite foreboding in the conceptual stage of the MOX factory, and could prove disastrous should licensing proceed and the plutonium plant actually be built and operated.

Contention 5. Incorrect Designation of Controlled Area.

DCS incorrectly designates the entire Savannah River Site as the controlled area of the MOX Facility. The proposed controlled area does not satisfy the NRC's requirement that a controlled area "means an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason," because DCS does not have control over the entire Savannah River Site. As a result of this improper controlled area designation, DOE improperly characterizes members of the public as MOX Facility workers for purposes of calculating radiological doses to the public during normal operations and accidents. DCS's incorrect assumption about the appropriate controlled area boundary also adversely affects the adequacy of its physical security measures. As a result, the design basis of the MOX facility is not adequate to support approval of construction. Another result is that the Environmental Report incorrectly minimizes the environmental impacts of the MOX Facility on the public, by defining the public in an overly narrow way. *See* Contention 8, *infra.*

Basis: The Environmental Report states that DCS plans to use the site boundary for the entire Savannah River Site as the controlled area boundary for the MOX Facility. Environmental Report at 4-1. The Savannah River Site is an approximately circular tract of land occupying 310 square miles, or 198,000 acres. *Id.* The MOX Facility is located on a much smaller parcel of land within "Separations Area (F Area)." *Id.* The MOX Facility occupies a 41-acre portion of the F area, whose area is 395 acres. *Id.* at 4-1, 4-2. According to DCS, there is a conventional PIDAS fence around the "protected area" of the MOX Facility, although DCS does not define what is meant by "protected area" in Section 4.1 of the Environmental Report.

As provided in 10 C.F.R. § 20.1003, the controlled area must be within the control of the licensee. The largest area around that MOX plant that is within the control of DCS consists of the "protected area" that lies within the boundary of the PIDAS fence.

GANE's concern is also supported by correspondence written by the NRC Staff to DCS. In a June 18, 2001, Request for Additional Information regarding the Environmental Report, the Staff asserted that "[I]n the first paragraph of section 4.1.1, note that the description of public access to the SRS area should include that fact that the NRC considers SRS workers who are not closely and frequently connected to the licensed activity and who are outside the MOX FFF restricted area and within the controlled area boundary to be 'members of the public.'" *Id.* at 12. In a February 28, 2001, RAI regarding the CAR, the Staff demanded that DCS "[r]evise the description of the controlled area boundary to include only those areas to which Duke Cogema Stone &

Webster DCS can limit access for any reason.'" *Id.*, par. 2. The Staff also ordered DCS to "[r]evise the description of Savannah River site workers who are outside the mixed oxide fuel fabrication facility (MFFF) restricted area but within the controlled area boundary that is provided in the second paragraph of Section 1.1.2.1 to state that these workers are deemed to be 'members of the public.'" *Id.*, par. 1.

In a July 12, 2001, RAI Response, DCS argues that the NRC has revised its policy with respect to the definition of workers who are considered to constitute "members of the public," such that under new 10 C.F.R. § 70.61, workers at other SRS facilities who are within the controlled area boundary of the Savannah River Site may be considered to be "workers" for purposes of assessing doses from the DCS operation. *Id.* at 12. This argument ignores the fact that the NRC has not changed the requirements for defining a controlled area. DCS simply has no legal basis for defining the controlled area boundary as the boundary of the entire Savannah River Site.

Contention 6. Inadequate Safety Analysis

The Safety Analysis (SA) submitted as part of the DCS Construction Authorization Request (CAR) is seriously flawed and provides neither a comprehensive assessment of all potential accident consequences nor a credible assessment of all potential accident likelihoods. The SA does not provide information of sufficient detail and quality to enable the NRC to make a determination pursuant to 10 CFR §70.23(b) that "the design bases of the principal structures, systems and components [of the MFFF] ... provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents."

In particular, the SA fails to correctly identify and carry out consequence assessments for accident scenarios with "bounding" consequences. The applicant's failure to identify the actual bounding accident scenarios implies that it has underestimated the consequences of these scenarios, and hence may not have applied engineered and/or administrative controls to the extent necessary to meet the performance requirements established in 10 CFR §70.61 and the defense-in-depth requirements of 10 CFR §70.64(b). In addition, the SA incorrectly considers the controlled area boundary of the MFFF to be coincident with the SRS site boundary when evaluating accident impacts to the public, which leads to projected doses to the public considerably below the correct values. Hence, the CAR SA fails to demonstrate that the MFFF as designed is likely to be in compliance with 10 CFR Part 70. NRC should therefore deny authorization of MFFF construction based on this document.

Basis: Pursuant to 10 CFR §70.22(f), "each application for a license to possess and use special nuclear material in a plutonium processing and fuel fabrication plant shall contain ... a description and safety assessment of the design bases of the principal systems, structures and components of the plant, including provisions for protection against natural phenomena ...". This "safety assessment" (SA) must provide information of sufficient detail and quality so that NRC can make a determination pursuant to 10 CFR §70.23(b) that "the design bases of the principal structures, systems and components [of the MFFF] ... provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents." It is understood that the objective of the SA is to demonstrate that "the design and design bases will result in a facility that will meet the performance requirements of 10 CFR §70.61 and the defense-in-depth requirement of 10 CFR §70.64(b)" (MFFF SRP, § 5.4.3.1E).

To demonstrate compliance with 10 CFR §70.61 performance requirements, the SA should include both a consequence assessment and a likelihood assessment (MFFF SRP, § 5.4.3.1E.iv). The SRP provides certain guidelines for these assessments. First, it states that the applicant's analysis of accident sequences should "examine the failure of

ALL features, structures, control devices, equipment or procedures to ensure that all principal SSCs are appropriately identified" (MFFF SRP, § 5.4.3.1E.ii.c).

Second, the SRP does not mandate that the applicant should "determine the consequences for all accidents and all SSCs individually," provided that "the applicant demonstrates that the consequence assessment is bounding through the applicant's analysis of representative processes sufficient to cover all principal types of hazardous materials" (MFFF SRP, § 5.4.3.1E.iii). Thus the applicant does not have to analyze the consequences of every conceivable accident sequence, provided that it conducts a limited number of analyses that it can demonstrate are "bounding."

The NRC staff has rightly pointed out a number of serious inadequacies of the ER and CAR safety assessments. First, it argues that the applicant has not provided adequate justification for its choice of "bounding" accidents. See June 8, 2001, RAI regarding ER (available on NRC MOX website). Second, it points out that the applicant has not provided sufficient information to determine the quantitative likelihoods of the accidents that it analyzes. See June 21, 2001 RAI regarding CAR at 39.

We find numerous examples in the CAR that illustrate the staff's concerns. For example, in at least one case, the internal fire (CAR, § 5.5.3.2), the CAR does not analyze a bounding case with respect to the source term. The case it does analyze --- a fire in the PuO_2 buffer storage unit --- is assumed to result in a bounding respirable airborne release fraction (RARF) of $6x10^{-4}$, based on a value from NUREG/CR-6410, the Nuclear Fuel Cycle Facility Accident Analysis Handbook.[15] This leads to an assumed airborne respirable release of 234 grams of PuO_2 into the glovebox. The SA then applies a leak path factor of 10^{-4} (corresponding to two banks of HEPA filters) to this result, so the release to the environment is assumed to be 0.023 g of PuO_2. However, every stage of the

[15] This is an error; the actual value for the RARF recommended by NUREG/CR-6410 is a factor of ten lower --- see the CAR RAI at 57.

analysis of this sequence contains questionable assumptions that require considerably more detailed justification than is provided in the CAR. The assumed value of the respirable airborne release fraction for plutonium dioxide powder exposed to fire conditions is taken from NUREG/CR-6410.[16] An examination of the origin of this value is warranted. It is based on a single set of experiments carried out in the 1960s on plutonium dioxide powder of unknown specifications. The relevance of these studies to the plutonium dioxide powder that will be stored and processed at the MFFF is unclear, which may have a completely different particle size distribution and respirable fraction. NUREG/CR-6410 itself contains this cautionary note:[17]

> "The biggest uncertainty is probably introduced by assuming that the experimentally determined RFs and ARFs for very specific powders apply universally. It is impossible to quantify the pertinent differences in powders for each application of this handbook. For aerosols ... these uncertainties coupled to the statistical uncertainties of the data probably overwhelm all other uncertainties ..."

An accident which is clearly bounding but is not analyzed in detail in the CAR is a hydrogen explosion in the sintering furnace. A previous safety study of MOX fuel fabrication plants has identified this scenario as one of the dominant risk contributors.[18] The amount of material at risk in the sintering furnace is 360 kilograms of MOX pellets, containing 20.2 kilograms of polished plutonium. This corresponds to a respirable

[16] U.S. NRC, "Nuclear Fuel Cycle Facility Accident Analysis Handbook," NUREG/CR-6410, March 1998, p. 3-71.
[17] Ibid., p. 4-1.
[18] Electric Power Research Institute (EPRI), "Status Report on the EPRI Fuel Cycle Accident Risk Assessment," EPRI NP-1128 (Interim Report), July 1979, p. 5-18. Relevant excerpts are attached as Exhibit 6.

airborne release of 200 grams of plutonium, using the CAR assumption of an RARF of 0.01 for MOX pellets exposed to an explosive detonation.

For the explosion event that was analyzed, the CAR applied a leak path factor of 10^{-4}, based on the assumption that two banks of HEPA filters will continue to operate normally during the fire. A similar assumption here would lead to the conclusion that 10 CFR §70.61 performance requirements would be met in this case.

However, NRC staff has appropriately questioned the applicant's assumption that the final stage of HEPA filters will maintain their design efficiency during "bounding " accidents, even those involving severe fires or explosives. An exhaustive data review of HEPA performance during accident conditions concludes that[19]

> "despite the many studies on HEPA filter performance under adverse conditions, there are large gaps and limitations in the data that introduce significant error in the estimates of HEPA filter efficiencies under DBA [design basis accident] conditions. Because of this limitation, conservative values of filter efficiency were chosen when there was insufficient data."

Thus even if the conditions are precisely known, the performance of HEPA filters during accidents is highly uncertain. But the CAR doesn't even provide basic information about accident conditions relevant to HEPA performance. Thus, it is impossible to quantitatively determine the likelihood that the HEPA filters will survive and thus determine if this accident is "highly unlikely," as required by 10 CFR §70.61.

If, as the NRC staff points out, "HEPA filters are unlikely to survive an explosion of the magnitude implied by the text" (CAR RAI at 60), this accident could lead to a violation of 10 CFR §70.61 performance criteria. A preliminary MACCS2 calculation indicates that the total effective dose equivalent (TEDE) to a member of the public at the MFFF restricted area boundary (approximately 200 meters from the plant stack) would exceed 25 rem unless the residual efficiency of the two-stage HEPA filter was better than 95%.[20] Thus, if one HEPA filter is severely damaged and the other degraded, this event would qualify as "high consequence" according to 10 CFR §70.61. However, only one principal SSC is applied in the CAR to prevent hydrogen explosions --- the "process safety I&C system" (CAR at 5.5-101). This raises the question of whether the current design meets the defense-in-depth requirements of 10 CFR §70.64(b).

The severity of this accident is consistent with the findings of the NRC staff, as detailed in its Response to Supplemental Filings on the Issue of Standing (p.4), that "an explosion ... in the absence of fully functional HEPA filters" could cause the dose to a receptor 20 miles from the facility to "approach the 5 to 25 rem range."

Thus the lack of detail in the CAR's SA, coupled with the large uncertainties involved in conducting the analysis, calls into question the applicant's conclusion that the MFFF plant design is likely to be in compliance with the performance requirements of 10 CFR §70.61. This can only be remedied if the applicant provides a comprehensive and quantitative safety assessment, with a full uncertainty analysis, at the design stage. Otherwise, the public can have no confidence that the plant will be safe if built as designed.

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[19] W. Bergman et al., "Criteria for Calculating the Efficiency of Deep-Pleated HEPA Filters With Aluminum Separators During and After Design-Basis Accidents," 23rd DOE/NRC Nuclear Air Cleaning and Treatment Conference, Buffalo, NY, July 1994.
[20] This assumes that the MFFF "controlled area boundary" is coincident with the "restricted area boundary" (see Contention 5).

ENVIRONMENTAL CONTENTIONS

Contention 7: ER Inadequate to Address the Environmental Impacts of Using MOX Fuel in the Catawba and McGuire Reactors

The ER is deficient because it does not provide an adequate analysis of the impacts of irradiating MOX fuel in the Catawba and McGuire reactors.

Basis: As discussed in Chapter 1 of the ER, the Department of Energy and DCS have designated four reactors to irradiate MOX fuel, McGuire 1 & 2 and Catawba 1 & 2. In Section 5.6.4, the ER addresses the environmental impacts of using MOX fuel in these four reactors by cross-referencing the DOE's Surplus Plutonium Disposition Final EIS (SPD FEIS).

All four of the Duke reactors have ice condenser containments. Although the SPD FEIS provides an analysis of the environmental impacts of burning MOX fuel in ice condenser containments (*See* Section 4.28), this discussion is inadequate because it does not take into account significant new information showing that the likelihood and consequences of an accident at a reactor that burns MOX fuel are substantially greater than previously believed. These impacts must be addressed in the Environmental Report, unless the DOE supplements the SPD FEIS pursuant to 40 CFR §1502.9(c) and 10 CFR §1021.314. (supplemental EIS required where there is "significant new ... information relevant to environmental concerns and bearing on the proposed action or its impacts"). The new information has been provided since January 4, 2000, when the SPD FEIS Record of Decision ("ROD") was issued.

The significant new information in question is contained in a technical report prepared by Sandia National Laboratories for the NRC that was issued in April 2000, *Assessment of the DCH [Direct Containment Heating] Issue for Plants with Ice*

Condenser Containments (NUREG/CR-6427).[21] NUREG/CR-6427 evaluates the vulnerability of U.S. nuclear plants with ice condenser containments to early containment failure in the event of a severe accident, where early containment failure is defined as that occurring within a few hours of initiation of core melt, and before effective evacuation of the public can take place. The study shows that "ice condenser plants are substantially more sensitive to early containment failure than PWRs [pressurized-water reactors] with large dry or subatmospheric containments" (Executive Summary, p. xix).[22] As NUREG/CR-6427 concludes, "ice condenser plants are at least two orders of magnitude more vulnerable to early containment failure than other U.S. PWRs." *Id. at 110.* This is because ice condenser containment structures have, on average, only one-half the ultimate failure pressure and containment volume of other PWR containments, and cannot withstand credible hydrogen combustion events. *Id. at 102.*

Sandia's new findings are of particular concern in view of the potential use of MOX fuel in Duke's ice condenser plants. The public health consequences of a severe reactor accident with containment failure and core dispersal will be significantly increased if MOX fuel is used, because of the greater concentrations of plutonium and

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[21] M. Pilch, K. Bergeron and J. Gregory, *Assessment of the DCH Issue for Plants with Ice Condenser Containments*, NUREG/CR-6427, SAND99-2553 (Albuquerque, NM: Sandia National Laboratories, April 2000). A copy of relevant pages is attached as Exhibit 7.

[22] We note that in the ROD for the SPD FEIS DOE states that "NRC has not considered it necessary to restrict operation of ... reactors in the United States that use ice condenser containments." The ROD also states that safety issues associated with MOX use in ice condenser plants "will continue to be evaluated," referring to comprehensive safety reviews to be performed by NRC. NUREG/CR-6427 is an example of such a comprehensive safety review, and its findings have a direct bearing on the environmental impact of DOE's plutonium disposition program.

other actinides in MOX cores compared to LEU cores.[23] This is exactly the type of accident to which Catawba and McGuire are particularly susceptible.

The risk of early containment failure is highest in the event of an accident occurring during a station blackout, since in that case the AC-powered hydrogen control system (glow plug igniters) would be disabled. In particular, the NRC report finds, in the event of an accident with station blackout, core melt and breach of the reactor vessel at high pressure, that the probability of early containment failure is 100% for Catawba and 98% for McGuire. Early containment failure is therefore a virtual certainty if this accident scenario were to occur at one of Duke's ice condenser units.

The total containment failure probability remains high even when all accidents are considered, including those in which AC power to the hydrogen control systems is maintained. Overall, the NRC report calculated that McGuire has a probability of early containment failure given core damage of 13.9%, exceeding NRC's screening criterion of 10%.[24] Based on these findings, NRC staff has recommended that new regulatory requirements for ice condenser plants be considered.[25]

NRC's new analysis of ice condenser containment failure also illustrates the weaknesses of the analyses carried out by Duke for the McGuire and Catawba *Individual Plant Examinations* (IPEs). These IPEs are relevant to the environmental analysis because DOE relied heavily on Duke's questionable IPE accident probability data in its

[23] Edwin S. Lyman, "Public Health Risks of Substituting Mixed-Oxide for Uranium Fuel in Light-Water Reactors," to appear in the journal *Science and Global Security*, October 19, 1998. A copy of the Executive Summary is attached as Exhibit 8.
[24] It should be noted that this result applies to core damage caused by internal events only. External events, such as earthquakes, floods and tornadoes, are associated with a substantially higher probability of station blackout than internal events. Therefore, if external events are also considered, the fraction of core damage events culminating in early containment failure will be significantly higher than this value.
[25] U.S. Nuclear Regulatory Commission, *Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and*

reactor accident analysis in the SPD Final EIS. (See SPD EIS, p. K-62). In particular, NRC's estimate of the McGuire early containment failure probability is seven times greater than Duke's own estimate of 2% (NUREG/CR-6427, p. xviii).

The findings contained in NUREG/CR-6427 clearly constitute "significant new information relevant to environmental concerns," requiring additional environmental analysis beyond what has been done in the SPD EIS. The ER is inadequate because it does not address this new information.

Contention 8. Impacts Minimized Through Incorrect Designation of Controlled Area.

As discussed above in Contention 5, DCS incorrectly designates the entire Savannah River Site as the controlled area of the MOX Facility. The proposed controlled area does not satisfy the NRC's requirement that a controlled area "means an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason," because DCS does not have control over the entire Savannah River Site. As a result of this improper controlled area designation, DOE improperly characterizes members of the public as MOX Facility workers for purposes of calculating radiological doses to the public during normal operations and accidents. Therefore, the Environmental Report incorrectly minimizes the environmental impacts of the MOX Facility on the public, by defining the public in an overly narrow way.

Basis: The basis for Contention 5 is adopted and incorporated by reference herein.

Recommendations on Risk-Informed Changes to 10 CFR 50.44 (Combustible Gas Control), SECY-00-0198, September 14, 2000.

Contention 9. Inadequate Cost Comparison

The Environmental Report does not provide any discussion of the costs of the proposed MOX Facility, or make a comparison to the costs of other alternatives.

Basis: 10 C.F.R. § 51.45(c) requires that an Environmental Report must include "consideration of the economic, technical, and other benefits and costs of the proposed action and of alternatives." In violation of this requirement, the Environmental Report offers no discussion of the economic costs and benefits of the proposed MOX Facility, or a comparison of the economic costs of other alternatives. The omitted costs include the costs of the MOX Facility itself, including costs of construction, normal operation, and accidents; the costs associated with secondary impacts, such as normal operation and accidents during transportation of feed material and finished fuel and the burning of the fuel in reactors. They include the economic costs of impacts to human health, and the economic costs of loss of habitable land through contamination.

To the extent that DCS may intend to rely on the Department of Energy's Surplus Plutonium Disposition EIS, the information provided in that report has been superseded by recent information from the DOE.[26] The estimated cost of disposition of plutonium as fuel (mixed oxide, or MOX) in commercial nuclear reactors has risen about 50% since 1999 to about $3 billion, while disposition via immobilization of plutonium in high-level nuclear waste has stayed flat since 1999 at about $1.5 billion. *Id.* at 3.1. This significant new information should be accounted for in the ER.

Contention 10. Inadequate Discussion of Transportation Impacts.

The transportation of plutonium pits and plutonium oxides to Savannah River Site threatens life and health along every transportation corridor, including the State of

Georgia which provides the most likely entranceway to South Carolina from the western states from which the plutonium shipments are expected to originate. Inadequate analysis of environmental impacts resulting from transportation has been performed in the 1999 Special Plutonium Disposition Environmental Impact Statement of the U.S. Department of Energy. This inadequacy has not been remedied by Duke Cogema Stone & Websters's Environmental Report at Section 1.2.6 which declares it "[r]elies on SPD EIS (DOE 1999)."

NEPA requires that all foreseeable impacts be analyzed. This licensing process should not be allowed to proceed until this substantial defect is cured.

Basis: GANE shares concerns expressed by the Georgia Department of Natural Resources in its comments to DOE submitted by James L. Setser, Chief, Program Coordination Branch of the Georgia Department of Natural Resources on September 21, 1998. The full text of the State of Georgia's comments may be found in the DOE's SPD EIS Volume III - Part A, pp. 148-176. The State of Georgia's comments with respect to emergency planning and safeguarding transportation shipments of plutonium remain unaddressed by either DOE or DCS in its Environmental Report.

Excerpts from the State of Georgia's comments meaningful to GANE's contention that transportation concerns have not been adequately addressed follow:

Transportation

The DEIS discusses in detail the analysis of both incident-free transportation and the effects of transportation accidents. The discussion below deals specifically with transportation of either plutonium metal or plutonium oxide to SRS under Alternatives 3 and 5, but also applies to transportation of "pit parts" and high-enriched uranium (HEU) components from Savannah River Site (SRS) to other

[26] National Nuclear Security Administration, Office of Fissile Materials Disposition, Report to Congress on the Life-Cycle Costs of the U.S. and Russian Fissile Materials Disposition Programs," Distribution Draft,

DOE facilities. It is assumed, based on information presented in the DEIS, that all shipments of plutonium or high-enriched uranium, including new Mixed Oxide (MOX) fuel shipments will be made using a Safe Secure Trailer (SST), operated by the Transportation and Safeguards Division (TSD) in DOE's Albuquerque office.

The State of Georgia further commented:

In July 1998, the DOE Deputy Assistant Secretary of Oversight issued a report titled "Independent Oversight Evaluation of Emergency Management Programs Across the DOE Complex." Included in this report is a critique of the TSD emergency management program. The Office of Oversight noted several "issues" related to TSD, including:

1) In September 1996, TSD management mandated the removal of radiation monitoring instruments from all convoy shipments ... [s]ome Emergency Action Levels (EALs) require radiation readings.

2) On November 1996, a TSD Safe Secure Trailer transporting nuclear weapons slid off a road and rolled over near Valentine, Nebraska. According to a Department of Defense Nuclear Command and Control System Support Staff report, almost four hours elapsed before DOE Headquarters was notified, and it was almost 20 hours before a Radiological Assistance Program (RAP) team determined that there had been no radiological release. The report recommended equipping convoys with radiological instruments to provide timely warning of potential personnel hazards. [GANE notes that this notorious incident happened *during a blizzard.*]

3) There is a discrepancy between an Emergency Action Level (EAL) in the TSD Hazards Assessment and the emergency management plan. One specifies an alert, while the other specifies a general emergency for the same conditions.

4) The document provided to Convoy Commanders to provide initial protective action recommendations for the public include decision paths that cannot be completed due to lack of observable criteria (requires information not directly observable or measurable).

5) The TSD hazards assessment (May 4, 1994) does not provide an adequate technical basis for ground transportation emergency planning, preparedness and response. No radiological assumptions, models, methodologies or evaluations for TSD convoy event hazards are documented or referenced in the TSD Hazards assessment.

6) The emergency response organizations, procedures and training for TSD and its contractor, Ross Aviation, do not adequately support accurate and prompt categorization and classification of operational emergencies during transport of nuclear materials or devices.

The DEIS discusses "24-hour-a-day real-time communications to monitor the location and status of all SST shipments via DOE's Security Communications system." For several years, state radiological emergency response organizations, including Georgia's have had access to the TRANSCOM real-time shipment tracking system. Particularly within the past year, the TRANSCOM system has proven to be unreliable in tracking of domenstic and foreign research reactor fuel shipments and Waste Isolation Pilot Plant (WIPP) dry-run shipments. It is our understanding that the Transportation and Safeguards Division (TSD) shipments use the same basic tracking software system, but states will not have access to the tracking information; nor will they have access to advance shipment information which normally precedes highway route control quantity (HRCQ) shipments of radioactive materials.

DOE responded that it follows "a path of continuous improvement in its transportation and emergency management programs" but then erroneously claims that the State of Georgia's comments are beyond the scope of its SPD EIS. DOE claimed to be working closely with State and tribal representatives to upgrade the TRANSCOM system but that SST/SGTs do not involve the use of TRANSCOM but has another system "to liaison with State transportation and safety organizations on SST/SGT shipments."

Georgia's dissatisfaction with DOE's responses were documented by internal memorandum dated September 1999:

> In dismissing Georgia's comments regarding transportation accidents, DOE's argument appears to be that since they have not experienced any serious accidents involving safeguarded shipments, that such accidents will not occur, and that Georgia should not be concerned about the consequences, both to emergency response personnel (who most likely will not have at their disposal the specialized equipment required to monitor for weapons-grade plutonium -- nor will the convoy crew) and the general public.
>
> . . .
>
> Comments regarding emergency preparedness capabilities during transport of radioactive materials ARE within the scope of the EIS, since transportation is essential to the overall success of the program. This is particularly true since the EIS itself, in Appendix L, page L-6, mentions that one of the key characteristics

of the SST/SGT system includes 'Established operational and emergency plans and procedures governing the shipment of nuclear materials.' Apparently DOE feels that it can choose which environmental impacts it wishes to include in the EIS.

. . .

[The system to liaison with State transportation and safety organizations on SST/SGT shipments] historically has not included state radiological emergency response personnel, despite repeated requests. DOE has been reluctant to discuss hazards associated with such shipments, even in the most generic terms.

In further comments (pp. 159-161) the State of Georgia has expressed:

The text of the DEIS describes the postulated accident scenarios as "the maximum forseeable offsite transportation accident", while Appendix L describes them as "the most severe accident conditions". We agree with DOE that Accident Severity Category VIII accidents would be considered "worst case" but assuming that such an accident can occur only in a rural setting does not appear to be conservative. For example, we note that "rural" mileage accounts for approximately 78% of the route between Pantex and SRS, while "suburban" mileage accounts for nearly 20% of the route. In the Atlanta metropolitan area, suburban speed limits outside I-285 are generally 65 miles per hour (mph); rural speed limits are 70 mph. Higher traffic volumes within the "suburban" area, and nearly equivalent speeds as in the "rural" area would seem to increase the relative probability of severe vehicle accidents in the "suburban" areas, and such accidents would potentially have far greater consequences than those presented in the DEIS.

The discussion of vehicle accidents specifically addresses the potential for a release of plutonium from the transport vehicle, with subsequent inhalation of plutonium by persons nearby. The DEIS however, states on page L-30, that "postaccident mitigative actions are not considered for dispersal accidents. For severe accidents involving the release and dispersal of radioactive materials into the environment, no postaccident mitigative actions, such as interdiction of crops or evacuation of the nearby vicinity, have been considered in this risk assessment."

The DEIS does not present sufficient information related to recovery. In Appendix K, which in general discusses the effects of facility incidents, the DEIS states "the longer-term effects of plutonium deposited on the ground and surface waters after the accident, including the resuspension and inhalation of plutonium and the ingestion of contaminated crops, were not modeled for the SPD (Surplus Plutonium Disposition) EIS. These pathways have been studied and been found not to contribute as significantly to dosage as inhalation, and they are controllable through interdiction". In previous correspondence with DOE in other programs, we have also met with some resistance to discussing the effects of deposited radioactive materials, as these effects were seen as being more "environmental" than "emergency response".

In order to plan for, equip themselves to deal with, and train their response personnel for dealing with a transportation incident involving plutonium, state and local officials need information regarding both immediate protective measures, and also information related to post-emergency issues such as resuspension and relocation of deposited radioactive materials. For example, regarding vehicular disturbances, Sehmel (1975) has examined the importance of auto and truck traffic in the increasing of resuspension. It was concluded that such disturbance, in the case of an asphalt surface with newly deposited material, will lead to increased resuspension, with a fraction resuspended of the order of 10^{-5} to 10^{-2} per vehicle passage. The higher rates occurred at speeds typical of freeway driving. After passage of about 100 cars only a small fraction of the original contamination remained on the road surface. Unless emergency officials promptly close the accident scene to vehicle traffic (an unlikely situation), emergency responders may face an incident scene that is, unknown to them, extremely hazardous due to respirable plutonium. Post-emergency actions may also be complicated due to the enhanced spread of contamination by vehicle traffic. It is worthy of note here that the DEIS presents no information regarding potential radiation doses to response personnel.

Public acceptance of transportation of plutonium (Pu) in the U.S. is not a given. The true risk posed by transportation of plutonium may indeed be very small, but it is not zero, and public perception regarding these risks, and public acceptance of them, is critical to the success of this program. The existence of knowledgeable emergency response personnel at the state and local level, armed with both the training and equipment which would be required to respond to a transportation incident involving plutonium is a critical component in obtaining this public acceptance.

The State of Georgia argued that:

DOE dismisses our comments regarding the consequences of plutonium deposition by claiming (a) that the consequences of plutonium inhalation are greater, and therefore bounding, and (b) that these consequences are predominantly economic. The long-term consequences of deposited radioactive materials, however, particularly plutonium, can result in significant public protective measures (condemnation of crops, interdiction, etc.) for significant land areas for an extended period of time, whereas the effects of plutonium inhalation are limited both in scope and duration. In addition, the EIS includes estimates of other economic impacts (such as the impacts of facility construction, transportation networks, etc.), so it is unclear how merely saying that an impact is "economic" automatically excludes such impacts from consideration in the EIS. In previous correspondence with DOE emergency preparedness personnel, DOE insisted that the effects of deposited radioactive materials were "environmental" effects instead of effects that should be considered in the development of planning basis documents for emergency preparedness. DOE can't have it both ways. These effects must be considered in at least one (and preferably both) contexts.

Further in the September 1999 Memorandum the State of Georgia responds to arguments from DOE (p. 159 of SPD EIS Vol. III - Appendix A) that accidents are less likely to occur in urban and suburban zones than rural zones with this observation:

> We contend that even a cursory review of accident statistics comparing accidents in the metropolitan Atlanta area to those in the rest of Georgia would not result in the reviewer reaching this conclusion. Increased traffic volume (particularly on I-285) and high speeds (approaching or even exceeding the "rural" speed limit) make accidents more numerous (and potentially more serious) on suburban and urban interstates that on rural interstates. We are aware of two (2) accidents in the metropolitan Atlanta area within the past several years in which accident forces (impact, crushing, fire) appear to have approached or even exceeded those for Class VIII accidents.

To underscore the concerns of the State of Georgia regarding support it can expect to receive in emergency response, a recent report by the Transportation Safeguards Division published a followup review the DOE Office of Oversight conducted in 1999, and the results of that review, as documented in the references below, contained the following findings:

1. The AL and TSD assessment and corrective action management programs have not been sufficient to identify emergency management program and performance weaknesses and to correct previously identified deficiencies.

2. TSD has not fully analyzed the hazards associated with TSD activities to permit decision-makers to respond effectively to all potential hazardous material emergencies. TSD lacks mechanisms to accurately categorize or classify an emergency and to formulate protective actions regardless of the incident location or source of the release.

3. TSD emergency responders did not demonstrate the ability to determine and communicate protective action recommendations in a timely manner and did not demonstrate adequate understanding of their relevance to public protection.

4. TSD has not established formal processes to ensure that offsite authorities and emergency responders are promptly and accurately notified of essential emergency information in accordance with DOE Order 151.1.

The Office of Oversight assessed TSD's Notification and Formulation of Protection Actions as "Unsatisfactory", meaning "the emergency management program being evaluated does not provide adequate assurance that site workers and the public can be protected following an emergency event or condition."

The Office of Oversight has not published any subsequent additional information regarding the status of the TSD Emergency Management Program.

Unlike other large radioactive materials shipments, agencies responsible for emergency preparedness and response will not have prior knowledge as to the route(s) and timing of these shipments, thus, TSD's ability to 1) assess the severity of an emergency, 2) develop protective measures, and 3) notify appropriate state / local authorities is of utmost importance. ("Emergency Management Program Follow-Up Review at the Albuquerque Operations Office Transportation Safeguards Division, December 1999, Prepared by Office of Oversight, Office of Environment, Safety and Health, U.S. Department of Energy)

These are serious issues raised by the State of Georgia and submitted to the public record which remain unaddressed. GANE appreciates the thorough and conscientious work of Georgia's Environmental Radiation Division and contends these efforts to protect public health and safety must be incorporated into the licensing process and the EIS under NEPA.

Contention 11. ER Fails to Address the Waste Stream from Aqueous Polishing.
ER understates the impacts of the waste stream from aqueous polishing to remove gallium, doesn't acknowledge problems with the same process in Europe, adds to burden of radioactive waste at SRS without designing a plan for managing the waste as required under NEPA.

Basis: DCS proposes to use "aqueous polishing" to remove gallium, americium and uranium from the weapons-grade plutonium oxide and acknowledges that the greatest volume and radioactivity of waste in the plutonium fuel fabrication process will result from this process. Besides the hazardous waste solvents laced with americium-241 and other alpha producing radionuclides, solid scrap plutonium is produced as a by-product of MOX pellet production which is then reprocessed for use in the overall process (ER 3.2, p.3-7). DCS attests to basing these processes on similar processes used at the COGEMA MELOX Plant and La Hague Plutonium Finishing Facilities in France (*id.*). This cannot be verified independently as all the data relevant to design, performance, waste volume and management, and environmental and worker safety for COGEMA's French operations are secret and unavailable to the public.

Conditions of La Hague operations are becoming known because contamination from the La Hague plant in the North Atlantic has been monitored and studied by Greenpeace and WISE-Paris. The record of COGEMA and data concerning MELOX and La Hague must be made available to members of the public in the United States. Indeed for this process to go forward with these records and other data unavailable to the intervenors fails to comply with both NEPA and NRC's Part 70 regulations since they cite experience gained there and processes used there as bases for the plutonium fuel factory at SRS.

When the plutonium disposition path was first proposed and embraced by SRS, DOE had put forth in its 1999 SPD EIS that a dry process called ARIES would be utilized to purify the plutonium pit feed material of gallium and other contaminants which degrade fuel cladding and undermine the fission process. Subsequently in DCS' ER it was identified that the aqueous process would be necessary which will produce over 81,000 gallons of mixed waste contaminated with alpha producing americium-241 in the order of nearly 80,000 curies (see calculations converting kg. to curies from State of Georgia below) per year (ER, Table 3-3, p. 3-51). Projected waste figures have risen rapidly from 0 to over 80,000 gallons in the last year. No plan has been proposed by DCS or NRC to accommodate this large amount of waste.

While not technically high-level waste, discussions center around utilizing DOE's high-level waste tanks in the F-Area Tank Farm. This is a horrific burden to Georgians and South Carolinians who have lived for 50 years with an inventory of 35,000,000 gallons of high-level liquid waste sitting in ever-aging tanks above the largest freshwater aquifer recharge area in North America. The proposed waste stream from aqueous polishing of plutonium oxides stands in stark contrast to the DOE's so-called tank-closure program which purports to be emptying and closing 24 of the tanks which violate EPA standards by 2022 and the other 27 tanks by 2030 (High-Level Waste Storage Tank

Closure, DOE/EIS-0303D, November 2000). The waste issue accompanying MOX manufacture is an egregious breach of trust between DOE and the population of South Carolina and Georgia. Even if the citizens of the area were willing to embrace having the tanks continuously filled with solvents contaminated with the largest inventory of radionuclides in the nation in contradiction to standing agreement to move towards tank closure, the fact remains that less than 1,000,000 gallons of space is available with no relief in sight given the recent failure of the program which prepares the liquid waste for solidification in the Defense Waste Processing Facility and leaks in the tanks #5 and #6 which have reduced the amount of space available in those tanks and caused waste to be moved to empty tanks scheduled for closure. The Defense Nuclear Facilities Safety Board maintains a website with weekly updates on the state of the tanks at SRS which may be viewed at www.dnfsb.org.

The changing climate, the left hand not knowing what the right hand is doing, and the moving target figures are yet more examples of the problems that are obvious even to lay members of the public with attempting to license an activity which has not yet been defined.

In recent comments to the NRC's EIS scoping for this license review the State of Georgia submitted this comment on the waste problem:

> As one small example of our "infrastructure" concerns, the applicant's Environmental Report contains the following statement, on page 3-15:
>
> > "Liquid high alpha activity waste (i.e., americium-241) will be transferred through a dedicated pipeline to the SRS F-Area Outside Facility. At the F-Area Outside Facility, the pH and the waste chemistry of the waste will be adjusted to conform to the WAC requirements for the F-Area Tank Farm. The F-Area Outside Facility is being upgraded through the addition of new tankage to be used for pretreatment of MOX process streams. The

liquid high alpha activity waste will be transferred to the F-Area Tank Farm and managed by SRS accordingly."

We note on page 3-51 that a portion of this high alpha waste stream, the "liquid americium stream", may contain up to 24.5 kg per year of Am-241. We first find it strange that the applicant, which obviously has a great deal of experience in dealing with radioactive materials, would choose to cite a quantity of radioactive materials using units of mass (kilograms) instead of activity (Curies or Bequerels), especially when the waste stream is so well characterized, and since another waste stream on the same page, the "acid recovery condensate", is characterized as having an activity of 10^8 Bq/yr. For the record, it appears that the "liquid americium stream" may involve the transfer of 79,000 Ci/yr (2.9×10^{15} Bq/yr) of Am-241 to the SRS F-Area Tank Farm. Over the life of the MFFF, it appears that more than 1,000,000 Ci (3.7×10^{16} Bq) may be added to the inventory of the F-Area Tank Farm. We are certain that NRC will agree that this matter deserves a more rigorous treatment in the EIS than the applicant provided in the above statement in the Environmental Report.

The waste problem is another example of DCS and NRC's "Ready-Shoot-Aim" approach to licensing the MOX fuel factory and must be stopped before more resources are wasted on licensing and definitely before ground is broken for this losing proposition or, God forbid, a cobbled-together plutonium factory is allowed to operate and threaten the lives and natural resources of the Southeastern United States.

Contention #12. SPD EIS and ER are deficient in their failure to analyze malevolent acts of terrorism and insider sabotage.

GANE contends that a license must not be given for construction and subsequently for operation of a plutonium fuel factory at the Savannah River Site which is situated on the border of Georgia on the Savannah River because it is vulnerable to malevolent acts such as terrorism and insider sabotage which could create an unacceptable beyond design basis accident. DOE did not analyze terrorism or insider sabotage in its Special Plutonium Disposition Environmental Impact Statement published in 1999. Neither did DCS in its 2000 Environmental Report which, while dismissing out-of-hand as inconsequential many credible scenarios, did not even acknowledge the real possibility of terrorism and insider sabotage (see Section 5.5 of the Mixed Oxide Fuel Fabrical Facility Environmental Report). This deficiency may be terminal to this licensing effort. In any event, malevolent acts must be analyzed as a foreseeable environmental impact under NEPA. Lack of analysis of the malevolent acts scenario leads to failure to design safeguards and failure to plan for emergency response and mitigation measures.

Basis: GANE agrees with the comments submitted by the State of Georgia Department of Natural Resources which raise the specter of malevolent acts and submits them here as substantive to our contention. The following text can be found as submitted on September 21, 1998 by James L. Setser, Chief, Program Coordination Branch of Georgia Department of Natural Resources in DOE's SPD EIS, Comment Response Document, Volume III - Part B at page 162:

> **Malevolent Acts**
>
> Several of the facility incidents discussed in Appendix K of the DEIS, particularly those events for which the initiating event is an "operator error," could also be intentionally initiated by an operator with malicious intent (an informed insider). It is unclear that the analyses presented in this DEIS consider malicious intent as

an incident initiator. A knowledgeable operator with malicious intent could disable or bypass systems which normally would be used to detect or mitigate an incident.

The transportation section of the DEIS, Appendix L, dismisses the possibility of malevolent acts with these words ... "[i]n no instance, even in severe cases such as discussed below, could a nuclear explosion or permanent contamination of the environment leading to condemnation of land occur. ... [s]uch attacks would be unlikely to occur ... [o]ther materials, including uranium hexafluoride, uranium oxide, TRU waste and LLW, are commonly shipped, and do not represent particularly attractive targets for sabotage or terrorist attacks".

We disagree with the conclusions drawn in this section of the EIS, and request that DOE perform calculations of the consequences of incidents initiated by malevolent acts, including transportation incidents. Results of these analyses should be classified as appropriate, as recommended by DOE Order 151.1, and incorporated into both this EIS and the Emergency Preparedness Hazard Assessment (EPHA) documents for both TSD and the plutonium facilities.

In its response to the State of Georgia, DOE responded that "[s]abotage scenarios are considered conjecture and not reasonably foreseeable." DOE goes on to say that "[t]he possibility of sabotage would be controlled through safeguards and security provisions including security requirements associated with facility workers." DOE's response concludes that "plutonium disposition facilities would be designed and operated in accordance with DOE Orders 470.1, *Safeguards and Security Program* and 151.1, *Comprehensive Emergency Management System*. The MOX facility ... would be subject to similar NRC requirements."

It is important to note here, that the CAR is deficient in regards to submitting information regarding the design of its safeguards and security program which weighs in at a mere two pages (Sec. 13). DCS states that it plans to submit the safeguards and security program at a later date, which as shown in the accompanying GANE Motion to Dismiss, is illegal both under NEPA and the NRC's own Part 70 requirements for licensing.

The State of Georgia states in its internal memo *Critique on DOE Comment Response, Surplus Plutonium Disposition Final Environmental Impact Statement, DOE/EIS-0283*, September 1999, that it remains unconvinced by DOE's attestment that malevolent acts are not a credible scenario for serious accidents:

> DOE is particularly insensitive to our concerns regarding malevolent acts including "insider sabotage," dismissing them as "conjecture." By dismissing these concerns, DOE can limit the consequences of spills, transfer errors and similar process upsets by assuming, for the sake of analysis, that all such events can be detected and mitigated within 10 minutes. Despite DOE's claim that this 10-minute duration does not result in truncation of source term (and reduction in the estimate of onsite and offsite consequences), such truncation does occur for process-related events such as the ones mentioned above.
>
> ...
>
> DOE elaborates in Appendix L (pages L-25 & 26) with the following statement: "This section provides an evaluation of impacts that could potentially result from a malicious act on a shipment of hazardous or radioactive material during transportation. In no instance, even in severe cases such as those discussed below, could a nuclear explosion or permanent contamination of the environment leading to condemnation of land occur. Because of the Transportation Safeguards System described in Appendix L.3.2, DOE considers sabotage or terrorist attack on an SST/SGT to be unlikely enough such that no further risk analysis is required."

> We are appalled at DOE's arrogance in this matter. DOE's own policies require the use of the Design Basis Threat (DBT) to determine event consequences and security requirements. DBT includes consideration of an insider as one potential threat vector. Particularly for facility scenarios, we contend that a knowledgeable insider could defeat detection mechanisms.

GANE contends that for the malevolent acts scenario to go unaddressed could lead to dire consequences for the population and natural environment of South Carolina and Georgia. Terrorism scenarios abound in the nightly news. Assault weapons and rocket launchers may be purchased by members of the civilian population not only on the black market but at weapons trade shows. News stories abound of employees at nuclear facilities around the world stealing special nuclear materials, to prove that they CAN or at least that's what they say when caught. However, it is not for the well meaning environmentalists of GANE to contemplate such evil, it is incumbent upon the NRC, DOE and DCS under NEPA that they must put their minds to the problem of safeguarding the world against the special problems posed by ultrahazardous materials such as plutonium. The population and the environment must be protected from terrorism, insider sabotage and theft of materials at every point in transporting and processing plutonium and uranium.

Contention 13. ER Lacks Probability Calculations.

The Environmental Report does not satisfy NEPA or the NRC's regulations because it contains an inadequate assessment of the probability and consequences of accidents.

Basis: As discussed in Contention 6, the accident analysis provided in the CAR is inadequate to satisfy NRC safety regulations. (Contention 6 is adopted and incorporated herein by reference.)

In addition, the ER's evaluation of accidents during operation is inadequate because it is not supported by a detailed license application describing how the facility will be operated. In the absence of such detailed information, the assessment of risk in the ER is merely speculative.

Finally, in violation of 10 C.F.R. § 51.45(d), the ER does not quantify the probability of accidents, nor does it explain why it is not "practicable" to quantify them. Probabilistic risks assessment is now commonly used and accepted by the NRC as a method for assessing accident risks. The NRC Commissioners have issued a number of decisions that address the issue of whether environmental impacts are worthy of consideration by looking at quantitative estimates of their probability. *See, e.g., Carolina Power & Light Co.* (Harris Nuclear Power Plant, Units 1 and 2), LBP-01-09, 53 NRC 239, *petition for review denied,* CLI-01-11, 53 NRC 370 (2001). In *Carolina Power & Light,* the Atomic Safety and Licensing Board ruled that the NRC Staff's probability of a certain accident sequence, 10-7, was so low as to be "remote and speculative." *Vermont Yankee Nuclear Power Corp.* (Vermont Yankee Nuclear Power Station), CLI-90-4, 31 NRC 333 (1990). In CLI-90-4, the Commission reversed a determination by the Appeal Board that an accident with a probability of 10^{-4} is remote and speculative, and remanded for development of more information on the plausibility or probability of the accident scenario at issue. *Id.*, 31 NRC at 335. The Commission ordered that if the Appeal Board found the probability of the entire accident sequence was 10^{-4} or more, it was to return the case to the Commission; otherwise, it was to make its own decision as to whether the probability was remote and speculative or not. *Id.* at 335-36. The Commission later clarified that low probability is the "key to applying NEPA's rule of reason" test to contentions alleging adverse environmental impacts from a specified accident scenario. *Vermont Yankee Nuclear Power Corp.* (Vermont Yankee Nuclear Power Station), CLI-90-7, 32 NRC 129, 131 (1990). The Environmental Report ignores these precedents and fails to provide quantitative estimates of accident probabilities. The requirement to expressing probabilities in quantitative terms is not excused by the existence of a qualitative standard in 10 C.F.R. § 70.61. Although there is overlap between NEPA requirements and Atomic Energy Act regulations, satisfaction of safety standards does not automatically guarantee that NEPA standards have been satisfied. *Limerick Ecology Action v. NRC,* 869 F.2d 719, 729-30 (3rd Cir. 1989). In this case, the NEPA requirement is even codified in the Part 51 regulations.

The contentions listed here establish that Georgia residents' life and property are threatened by manufacturing plutonium fuel at Savannah River Site.

These many serious safety issues weaken already shaky defenses of a messy, expensive and risky process to make a dangerous, experimental fuel to load in decrepit, vulnerable Southeastern reactors with the shallow goal to dispose of a mere 1 percent of genuinely problematic plutonium.

GANE supports a cautious, open inquiry into plutonium immobilization at Savannah River Site. The same wastes which were generated in the initial manufacture of plutonium pose an ever-present danger to the Savannah River Basin and the prospect to vitrify those wastes into a protective safeguard for weapons plutonium is appealing. Immobilization processes, though risky, do not require several of the messiest steps with the most obnoxious waste streams associated with MOX and will more effectively provide a barrier to re-use of plutonium stocks, a goal which MOX is unable to achieve.

We appreciate the Commission's establishment of a full panel of judges to hear GANE"s and the other intervenors compelling issues. We appreciate your most thoughtful consideration of GANE's Motion to Dismiss Licensing Proceeding or, in the Alternative, Hold It in Abeyance and believe you will find these contentions will contribute to your finding that it is illegal and improper to proceed with this licensing review until a proper Hearing Record is achieved.

Respectfully submitted,

Glenn Carroll
GANE - Georgians Against Nuclear Energy

dated August ~~13~~ 14, 2001 in Decatur, Georgia

GANE - Georgians Against Nuclear Energy
P.O. Box 8574
Atlanta, GA 30306
404-378-9542

LIST OF EXHIBITS

Exhibit 1. Declaration of Dr. Edwin S. Lyman In Support of GANE's Contentions (August 13, 2001).

Exhibit 2. Declaration of Peter Burkholder in Support of GANE's Contentions (August 13, 2001)

Exhibit 3. Excerpts, B.H. Erkilla, P.M. Rinard, K.E. Thomas and N.R. Zack (Los Alamos National Laboratory), C.D. Jaeger (Sandia National Laboratories), "Design Impacts of Safeguards and Security Requirements for a U.S. MOX Fuel Fabrication Facility," Los Alamos National Laboratory report LA-UR-97-4691, November 1997

Exhibit 4. Letter from Eric Leeds, NRC's Chief of Special Projects Branch, Division of Fuel Cycle Safety and Safeguards in the Office of Nuclear Material Safety and Safeguards to Patrick Rhoads, DOE Office of Fissile Materials Disposition, National Nuclear Security Administration (July 11, 2001)

Exhibit 5. Talwani, et al., Recurrence Rates of Large Earthquakes in the South Carolina Coastal Plain Based on Paleoliquefication Data, Journal of Geophysical Research, Vol. 106, April 2001. p. 6621.

Exhibit 6. Electric Power Research Institute (EPRI), "Status Report on the EPRI Fuel Cycle Accident Risk Assessment," EPRI NP-1128 (Interim Report), July 1979 (relevant excerpts)

Exhibit 7. M. Pilch, K. Bergeron and J. Gregory, *Assessment of the DCH Issue for Plants with Ice Condenser Containments*, NUREG/CR-6427, SAND99-2553 (Albuquerque, NM: Sandia National Laboratories, April 2000.

Exhibit 8. Executive Summary: Edwin S. Lyman, "Public Health Consequences of Substituting Mixed-Oxide for Uranium Fuel in Light-Water Reactors"

Exhibit 9. Coeytaux, Faid & Schneider, "Waste Production in French MOX Fabrication Facilities," WISE-Paris.

EXHIBIT 1

August 13, 2001

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
Thomas S. Moore, Chairman
Charles N. Kelber
Peter S. Lam

In the Matter of	)	
DUKE COGEMA STONE & WEBSTER	)	Docket No. 0-70-03098-ML
(Savannah River Mixed Oxide Fuel Fabrication Facility)	)	ASLBP No. 01-790-01-ML

DECLARATION OF DR. EDWIN S. LYMAN
IN SUPPORT OF GANE'S CONTENTIONS

Under penalty of perjury, Edwin S. Lyman declares as follows:

1. My name is Edwin S. Lyman. I am scientific director of the Nuclear Control Institute ("NCI"), is a non-proliferation research and advocacy organization located in Washington, D.C.

2. I am a qualified expert on nuclear safety and safeguards issues. I hold a PhD, a master of science and a bachelor's degree in physics. For over nine years, I have conducted research on security and environmental issues associated with the management of nuclear materials and the operation of nuclear power plants. I have published articles in journals and magazines, including *The Bulletin of the Atomic Scientist* and *Science and Global Security*. A copy of my resume, including a partial list of publications and invited speeches, is attached.

3. I am familiar with the licensing-related filings and correspondence that have been submitted by Duke Cogema Stone & Webster ("DCS") in this proceeding, including the Construction Authorization Report, the Quality Assurance Plan, and the Environmental Report. I am also familiar with regulations and guidance of the U.S. Nuclear Regulatory Commission ("NRC") and the U.S. Department of Energy ("DOE") governing plutonium processing facilities. In addition, I am familiar with the requirements of the National Environmental Policy Act.

4. On behalf of GANE, I have reviewed the licensing documents for the proposed MOX Facility, and assisted GANE with the preparation of contentions regarding deficiencies in those licensing documents.

5. I assisted in the preparation of GANE's contentions regarding Safeguards, Physical Security, the Environmental Impacts of Using MOX Fuel in the Catawba and McGuire Reactors, and the Accident Analysis Under 70.61. The factual assertions in these contentions are true and correct to the best of my knowledge and belief, and the opinions expressed therein are based on my best professional judgment.

PhD

Edwin S. Lyman, Ph.D

August 13, 2001

Edwin Stuart Lyman
Curriculum Vitæ

Born 21 June 1964, New York, NY; Citizenship: USA; Marital status: single.

Address:

Nuclear Control Institute, 1000 Connecticut Avenue N.W., Suite 410, Washington, DC 20036, USA.

Phone: (202) 822-6594
Fax: (202) 452-0892. E-mail: lyman@nci.org

Education:

Ph.D, Cornell University, Theoretical Physics, August 1992.
M.S., Cornell University, Physics, January 1990.
A.B., *summa cum laude*, New York University, Physics, June 1986; Phi Beta Kappa.

Recent Professional Experience:

July 1995-Present: Scientific Director, Nuclear Control Institute, Washington, D.C.

August 1992—June 1995: Postdoctoral research associate, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ. Studies included technical and policy issues related to the disposition of surplus fissile materials; assessments of materials for encapsulation of nuclear wastes; proliferation, social and environmental aspects of international programs for the management of spent nuclear fuel and reprocessing wastes.

Spring 1995: Preceptor for Environmental Studies 302, "Perspectives on Environmental Issues: Values and Policies."

Spring 1994: Lecturer, Woodrow Wilson School. Preceptor for WWS 304, "Science, Technology and Public Policy."

July 1988—June 1992: Graduate research assistant, Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, NY. Conducted thesis research on high-energy physics under the supervision of Prof. S.H.-H. Tye.

August 1986- June 1988: Andrew D. White Graduate Fellow, Physics, Cornell University.

Partial List of Publications, Solicited Reports and Letters:

Invited talks:

E. Lyman, "Perspectives on New Plant Licensing," U.S. Nuclear Regulatory Briefing on Readiness for New Plant Applications and Construction, Washington, DC, July 19, 2001.

E. Lyman, "Regulatory Challenges for Future Nuclear Plant Licensing: A Public Interest Perspective," Advisory Committee on Reactor Safeguards (ACRS) Workshop on New Nuclear Plant Licensing, Washington, DC, June 5, 2001.

E. Lyman, "The Future of Nuclear Power: A Public Interest Perspective," 2001 Symposium of the Northeast Chapter of Public Utility Commissioners, Mystic, CT, May 21, 2001.

Conference Papers:

E. Lyman, "The Future of Immobilization Under the U.S.-Russian Plutonium Disposition Agreement," 42nd Annual Meeting of the Institute of Nuclear Materials Management, Indian Wells, CA, July 18, 2001.

P. Leventhal and E. Lyman, "Who Says Iraq Isn't Making a Bomb?" International Herald Tribune, November 2, 1995.

E. Lyman, "Prospects and Unsolved Issues for Plutonium Immobilization," invited talk, INESAP/IANUS/UNIDIR Fissile Cutoff Workshop, Palais des Nations, Geneva, June 1995.

E. Lyman, "An Intermediate Solution for Plutonium from Dismantled Nuclear Warheads," invited talk, Meeting of the German Physical Society, Berlin, Germany, March 1995.

E. Lyman, "The Sea Transport of High-Level Radioactive Waste: Environmental and Health Concerns," invited talk, Channel Islands International Conference on Nuclear Waste, St. Helier, Jersey, United Kingdom, January 1995.

E. Lyman, "Safety Issues in the Sea Shipment of Vitrified High-Level Radioactive Wastes to Japan," report sponsored by the Nuclear Control Institute, Greenpeace International and Citizens' Nuclear Information Center Tokyo, December 1994.

E. Lyman, "Interim Storage Matrices for Excess Plutonium: Approaching the 'Spent Fuel Standard' Without the Use of Reactors," PU/CEES Report No. 286, Center for Energy and Environmental Studies, Princeton University, August 1994.

E. Lyman, "Disposition of Military Spent Fuel in the United States," Sixth International Summer Symposium on Science, World Affairs and Arms Control, Oberwesel, Germany, July 1994.

H. Feiveson and E. Lyman, "No Solution to the Plutonium Problem," Washington Post, July 29, 1994.

E. Lyman, "Getting Rid of Weapon Plutonium," *Bulletin of the Atomic Scientists,* July/August 1994.

E. Lyman, "Assessing the Proliferation and Environmental Risks of Partitioning-Transmutation," Fifth International Summer Symposium on Science and World Affairs, Cambridge, MA, USA, July 1993.

E. Lyman, F. Berkhout and H. Feiveson, "Disposing of Weapons-Grade Plutonium," *Science* **261** (1993) 813.

E. Lyman, "The Solubility of Plutonium in Glass," PU/CEES Report No. 275, Center for Energy and Environmental Studies, Princeton University, April 1993.

F. von Hippel and E. Lyman, "Appendix: Probabilities of Different Yields," addendum to J. Mark, "Explosive Properties of Reactor-Grade Plutonium," *Science and Global Security* **4** (1993) 125.

F. Berkhout, A. Diakov, H. Feiveson, H. Hunt, E. Lyman, M. Miller, and F. von Hippel, "Disposition of Separated Plutonium," *Science and Global Security* **3** (1993) 161.

P. Argyres, E. Lyman and S.H.-H. Tye, "Low-Lying States of the Six-Dimensional Fractional Superstring," *Phys. Rev.* **D46** (1992) 4533.

S.-w. Chung, E. Lyman and S.H.-H. Tye, "Fractional Supersymmetry and Minimal Coset Models in Conformal Field Theory," *Int. J. Mod. Phys* **A7** (1992) 3337.

EXHIBIT 2

August 13, 2001

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
Thomas S. Moore, Chairman
Charles N. Kelber
Peter S. Lam

In the Matter of	)	
DUKE COGEMA STONE & WEBSTER	)	Docket No. 0–70–03098–ML
(Savannah River Mixed Oxide Fuel Fabrication Facility)	)	ASLBP No. 01–790–01–ML

DECLARATION OF PETER BURKHOLDER IN SUPPORT OF GANE'S CONTENTIONS

Under penalty of perjury, Peter Burkholder declares as follows:

1. My name is Peter Burkholder. I am a private consultant in the field of seismology, and an a qualified expert on continental seismology.

2. I hold a Master's Degree in seismology from the University of Wisconsin in Madison, Wisconsin. For over ten years, I have conducted or supported seismological research on the Baikal rift zone of Siberia, on the West Antarctic ice sheet, and on the Kaapvaal craton of southern Africa. **A copy of my resume is attached.**

3. I am familiar with the licensing–related filings and correspondence, and portions thereof, that relate to seismological issues under review in this proceeding. These documents include Duke Cogema Stone & Webster's ("DCS's") Construction Authorization Report and the Environmental Report. I am also familiar with regulations and guidance of the U.S. Nuclear Regulatory Commission ("NRC") which pertain to seismological design.

4. On behalf of GANE, I reviewed the relevant portions of licensing documents for the proposed MOX Facility, and assisted GANE with the preparation of contentions regarding deficiencies in those licensing documents.

5. I assisted in the preparation of GANE's contention regarding Inadequate Seismic Design. The factual assertions in these contentions are true and correct to the best of my

knowledge and belief, and the opinions expressed therein are based on my best professional judgment.

Peter Burkholder

August 13, 2001

Peter Burkholder

2229 S. Gilpin Street, Denver, Colorado 80210-4616 303/282-7738 pburkholder@pobox.com

Education and Training

University of Wisconsin - Madison Madison, Wisconsin
M.S. Geophysics/Seismology 1991-1996
Thesis: Three-dimensional teleseismic tomography of the Baikal Rift zone

Earlham College Richmond, Indiana
B. A. Physics Graduated *Cum Laude,* 1987

Honors/Awards
AAAS Science & Media Fellow with *Newsweek* magazine, 1996
U. Wisconsin Graduate School Honors Fellow
Phi Beta Kappa
National Merit Scholar

Professional Experience

Applied Physics Lab, University of Washington Seattle, Washington
Senior Computing Specialist, IT Security Manager March-July 2000, January-May 2001

Applied Physics Lab, University of Washington Seattle, Washington
Senior Computing Specialist, Interim Computing Services Manager July-December 2001

Geophysics Program, University of Washington Seattle, Washington
Research Scientist September 1998-March 2000, March 2001-present
- Ran Spyder system for gathering global earthquake data and providing web data access
- Evaluated station seismic response for quality control and site characteristics

Department of Geophysics, University of the Witwatersrand Johannesburg, South Africa
Systems Engineer April 1997-September 1998
- Provided technical and scientific support to the Kaapvaal craton field seismology program
- Installed and serviced 14-station seismic network across northern South Africa

Department of Geology and Geophysics, University of Wisconsin-Madison Madison, Wisconsin
Research Associate June 1991 - December 1996
- Analyzed seismic data from field programs, prepared research reports and presentations

St. Andrew's Episcopal School Bethesda, Maryland
Physics Teacher August 1988-June 1990
- Taught three tracks of high-school physics, introduced computer-based labs to curriculum

Publications and Abstracts:

Teleseismic Tomography of the Baikal Rift Zone. P.D. Burkholder. M.S. Thesis, Univerisity of Wisconsin-Madison, 1996.

Teleseismic Tomography Reveals Anomalous Mantle Beneath the Baikal Rift: P D Burkholder, R P Meyer, L L Delitsin, AGU 1995 Spring meeting.

A Crustal Seismic Study in West Antarctica. T S Clarke, P D Burkholder, C R Bentley, S B Smithson. IUGG XXI General Assembly, Boulder, Colorado, USA, 1995.

EXHIBIT 3

LA-UR-97-4691
November 1997

Design Impacts of Safeguards and Security Requirements for a US MOX Fuel Fabrication Facility

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Executive Summary

This document was prepared for the Office of Materials Disposition of the Department of Energy (DOE). It is a follow-up document to "Safeguards and Security Considerations for a Mixed Oxide Fuel Fabrication Facility." It reviews US requirements for safeguards and security as applied to a mixed-oxide (MOX) fuel fabrication facility and the facility design implications of these requirements. The intended users are potential bidders for the construction and operation of the facility.

The document emphasizes the relevant DOE Orders. During the preparation of the document there was indication that material control and accountability (MC&A) may fall under the Nuclear Regulatory Commission (NRC) regulatory process. Accordingly, where the requirements are significantly different, the NRC requirements are highlighted

Although the Orders are reviewed for completeness, the areas that influence facility design are emphasized. While many of the materials accounting requirements do not directly contribute to the building design, careful attention must be given to the measurement, monitoring, and data-gathering requirements for the facility. These aspects of a near-real-time accounting system can play an important role in planning processing operations and floor-space requirements within the process and storage areas. Throughout this document the authors have tried to point out how a requirement for safeguards and security might impact the design of the building and internal operations features.

A modern plutonium-handling facility should incorporate as much automation, instrumentation, and computing as possible to meet the needs of NRC, DOE, and the International Atomic Energy Agency (IAEA). All routine aspects of moving and handling the materials should be automated, from receipt of the feed material to loading of the assembly transports. Data gathering for MC&A should be automated, as well, making use of bar-code readers and connections of measurement equipment, particularly balances, to the computer system. Thus, careful consideration will have to be given to the location of MC&A stations, measurement equipment, etc., in the design of the facility. In addition, many of the monitoring and inventory operations are most effective when automated and continuous. If these features of a modern safeguards and security system are not designed into the facility, it may not be possible to meet DOE and NRC regulations or IAEA safeguards criteria without expensive and time-consuming facility shutdowns and increased personnel radiation exposure. In some cases, retrofitting may be needed, but may not be possible.

Introduction

In July 1997 a document was released, "Safeguards and Security Considerations for a Mixed Oxide Fuel Fabrication Facility," that presented initial thoughts on the application of safeguards and security for such a facility. This follow-up document provides a more in-depth review of safeguards and security requirements and their impact on facility design. The discussion is centered around the Department of Energy (DOE) Orders, DOE O 5633.3B and DOE O 5632.1C and manuals. During the preparation of this document, there was indication that material control and accountability (MC&A) would be regulated by the Nuclear Regulatory Commission (NRC). Therefore, where DOE and NRC requirements differ significantly, the authors have highlighted this and provided guidance on the impact of this difference to facility design. Finally, International Atomic Energy Agency (IAEA) safeguards impacts on facility design are discussed.

Chapters I–III are structured similarly to the requirements in DOE O 5633.3B. Chapter IV is devoted to the security requirements of DOE O 5632.1C. NRC MC&A regulations, where they differ from DOE requirements, are highlighted in Chapter V. Finally, IAEA safeguards issues are reviewed in Chapter VI. An approach to the use of nondestructive assay (NDA) in materials accounting and verification measurements for a MOX fuel fabrication facility is presented in Appendix 1; a bibliography is also provided for additional information. Background information on application of MC&A and IAEA safeguards for a modern MOX fuel fabrication facility may be found in the literature listed in Appendix 2.

Although many of the security requirements have a direct bearing on facility design, many of the requirements for MC&A in both the DOE and NRC regulations are more administrative in nature. Both NRC and DOE MC&A requirements require extensive documentation of safeguards design and practices at the facility. This information is part of the basis for NRC licensing of the facility. This document recognizes that such documentation and procedures are required, but focuses instead more upon the technical requirements that have an influence on facility design. While a cursory inspection of the requirements may lead one to believe that MC&A has little impact on facility design, there are many issues involving measurement capability and location and data handling, manipulation, and retention that can directly impact floor-space requirements, electrical demands, movements of materials in transport systems, and the need for automation. Both domestic and international safeguards strategies must be considered when designing the MOX fuel fabrication facility. If these capabilities are not designed into the facility, it may not be possible to retrofit them into the facility and, consequently, to meet the requirements. Retrofitting safeguards into the facility may be prohibitively expensive.

Chapter I

Basic MC&A Requirements

Facility Structural Design

Facility and operation design shall take into account threats concerning the theft or diversion of nuclear materials and radiological sabotage as specified in the "Design Basis Threat Policy for the Department of Energy Programs and Facilities (U)" as issued by the DOE Office of Security Affairs (NN-50). Additionally, safeguards and security and the overall facility will be designed to mitigate emergency conditions stemming from the possible loss of control of special nuclear material (SNM).

At each main stage of the design process, a safeguards and security vulnerability assessment (VA) shall be performed on the facility design to determine if the design meets the intent of the DOE Orders for preventing and detecting theft or diversion of nuclear materials. This VA evaluates the potential for unauthorized accumulation of a target quantity of plutonium from multiple locations throughout the facility. To assure compliance with the Orders, nuclear materials cannot be received, processed, or stored at facilities until authorization has been granted in accordance with requirements of DOE O 5634.1B, "Facility Approval, Security Surveys, and Nuclear Materials Surveys."

DOE Office of Safeguards and Security personnel shall be briefed at appropriate times throughout the design process concerning the safeguards and security systems and design for the MOX fuel fabrication processes and associated facilities. By agreement with the US, the International Atomic Energy Agency (IAEA) must have access to those portions of the design designated to process and handle materials that have been identified by the US to be placed under IAEA safeguards. The IAEA may recommend modifications to portions of the design to facilitate their inspection or remote monitoring activities. See Chapter VI for more information.

Training Design Requirements

DOE requires that all facility personnel performing MC&A activities be trained and qualified to perform their duties at the MOX fuel fabrication facility. In this regard, facility space must be dedicated and adequately equipped to permit routine, representative training, qualification, and requalification of analytical laboratory technicians and assay personnel, materials handlers/transferors, nuclear materials custodians, operational and process workers, security forces, data entry personnel, appropriate management personnel, and MC&A operational personnel.

Accountable Nuclear Materials

All nuclear material in the MOX fuel fabrication facility will be controlled and accounted for according to DOE O 5633.3B and its associated manuals. Accounting for and controlling nuclear materials indicate that special requirements must be included in the facility design that are specifically addressed in the DOE Orders and this document. Nuclear materials transactions must be reported to the facility accounting system and the Nuclear Materials Management Safeguards System (NMMSS) to maintain an up-to-date nuclear materials inventory. The MOX fuel fabrication facility accounting-system network shall be capable of interfacing and furnishing appropriate data to the NMMSS national accounting system that tracks all nuclear materials in the US. See Chapter II for more information.

Nuclear materials that will be used in the fuel fabrication processes include depleted and natural uranium, low-enriched uranium, ^{241}Am, and plutonium (highly enriched in isotope ^{239}Pu). All of these are accountable nuclear materials. Depleted and natural uranium are considered "source materials" and accountable at the kilogram quantity level. Enriched uranium and plutonium are

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 11, 2001

EXHIBIT
#4

Mr. Patrick Rhoads
Office of Fissile Materials Disposition
National Nuclear Security Administration
U.S. Department of Energy
Washington, DC 20585

Dear Mr. Rhoads

On February 28, 2001, Duke, Cogema, Stone and Webster (DCS) submitted to the U.S. Nuclear Regulatory Commission (NRC) its construction authorization request for the mixed oxide fuel fabrication facility (MOX FFF). DCS expects to submit an application for operations next summer. To support our review of these and related safety documents, additional training of our staff in plutonium processing environments, especially with weapons-grade plutonium, would be beneficial. We believe the best and perhaps only place to acquire this type of training is at Los Alamos National Laboratory (LANL), a U.S. Department of Energy (DOE) contractor.

We are prepared to procure the training services directly from LANL; however, procuring these services through NRC's administrative processes may not be timely. Since we both understand the schedule requirements associated with the MOX FFF, we request that DOE arrange with LANL to convene and conduct the training directly. We believe that authorizing LANL directly will save as much as six months. We recognize that direct funding represents no additional financial burden to DOE since the training costs would otherwise be costed indirectly to DOE through your contract with DCS. In fact, some administrative costs may be obviated. DOE would be free to send any of its staff or its contractors to the training along with the NRC staff.

If you have any questions on this request, please feel free to call Vanice Perin at 301-415-8143.

Sincerely,

Eric Leeds, Chief
Special Projects Branch
Division of Fuel Cycle Safety
and Safeguards
Office of Nuclear Material Safety
and Safeguards

cc:
R. Ihde, DCS
P. Hastings, DCS
J. Johnson, DOE
H. Potter, SC Dept. of HEC
J. Conway, DNFSB
E. Foster
G. Carroll, GANE
R. Thomas, Environmentalists, Inc.
F. Motley, LANL
D.Moniak, BREDL

EXHIBIT 5

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. B4, PAGES 6621–6642, APRIL 10, 2001

Recurrence rates of large earthquakes in the South Carolina Coastal Plain based on paleoliquefaction data

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Abstract. We present a reanalysis of results of 15 years of paleoliquefaction investigations in the South Carolina Coastal Plain. All earlier radiocarbon age data and locations of organic material collected by various investigators were reviewed and recalibrated to obtain a uniform data set. The calibrated dates and the spatial extent of the sandblows having similar dates were used to estimate ages and magnitudes of prehistoric earthquake episodes. The results of this analysis suggest seven episodes (episodes A–G) of prehistoric liquefaction in the past 6000 years and two possible scenarios for their occurrence. In the first scenario, three seismic sources exist within the Coastal Plain of South Carolina; at Charleston (A, B, E, and G) with magnitudes *M* 7+, Georgetown (C and F), and Bluffton (D) with magnitudes *M* ~6. In the second scenario, episodes C and D are combined into one episode, episode C′. In this scenario all earthquakes occurred at Charleston and with *M* 7+. Episodes A and B seem to be more representative of the earthquake cycle and suggest a recurrence time of 500–600 years for *M* 7+ earthquakes at Charleston. The recurrence times and magnitudes for episodes C and D are estimated at ≥2000 years and ~6.0, respectively. The older episodes are less frequent, a fact that may be attributable to times of low ground water table. Before ~6000 years B.P., the ground water table was too low to permit observable liquefaction features to develop at the surface.

1. Introduction

Historical records, including over 2000 accounts, of felt earthquakes in South Carolina go back as far as 1698 [*Bollinger and Visvanathan*, 1977; *Visvanathan*, 1980]. To extend the historical record further back in time, paleoseismological investigations, started more than a decade ago, identified and dated paleoliquefaction features preserved in the shallow Coastal Plain sediments (Figure 1). Sand expulsion features known as sandblows, which result from seismically induced liquefaction, are preserved in the shallow sediments of the South Carolina Coastal Plain (SCCP) and provide information that can be used to construct the prehistoric earthquake record. Since the discovery of the first prehistoric sandblow in South Carolina [*Cox and Talwani*, 1983], there have been concerted efforts to document the extent of these sandblows in South Carolina (section 2). The information from these investigations helps to assess the potential seismic hazard in South Carolina. In this study we present an analysis of the spatial and temporal extent of these liquefaction data, in order to obtain the recurrence times and estimate magnitudes of prehistoric earthquakes that formed the sandblows.

2. Early Studies

The first systematic search of a paleoliquefaction feature in South Carolina was conducted by *Cox* [1984] and led to the discovery of a sandblow at Warrens Crossroads located ~40 km west of Charleston, South Carolina, which was caused by the 1886 earthquake (Figure 1). Detailed mapping and soil sampling showed the source sand to be a clean, white, mica rich sand layer approximately 2.7 m thick and located ~2.3 m below the surface [*Cox and Talwani*, 1983]. Shallow trenching at this site showed that the sandblow formed by the upward movement of sand toward the surface along a feeder dike that widened from 20 cm at the base of the trench to approximately 0.6 m at the ground surface. Clasts of surface soil had slumped into the sandblow shortly after it developed. Even though this study did not uncover any pre-1886 features, it suggested that sandblows and other structures can be preserved in the soils of the SCCP and that areas which experienced liquefaction during the 1886 earthquake might contain sandblows that developed in prehistoric earthquakes of magnitude similar to that of the 1886 earthquake [*Cox*, 1984].

This discovery was followed by intensive studies by the U.S. Geological Survey in the mid-1980s, by Ebasco Services in the early 1990s, and by the University of South Carolina sporadically since 1983. These studies were primarily aimed at discovering the spatial extent of paleoliquefaction features and developing criteria for their identification. S. F. Obermeier and R. E. Weems of the U.S. Geological Survey and their coworkers were the first to discover sandblows that predated 1886. Following their initial discovery of a prehistoric sandblow at Hollywood, they discovered several additional sandblows in other parts of the SCCP [*Obermeier et al.*, 1987]. D. C. Amick, R. Gelinas, and their coworkers from Ebasco Services discovered other sandblows in the SCCP and extended the search for

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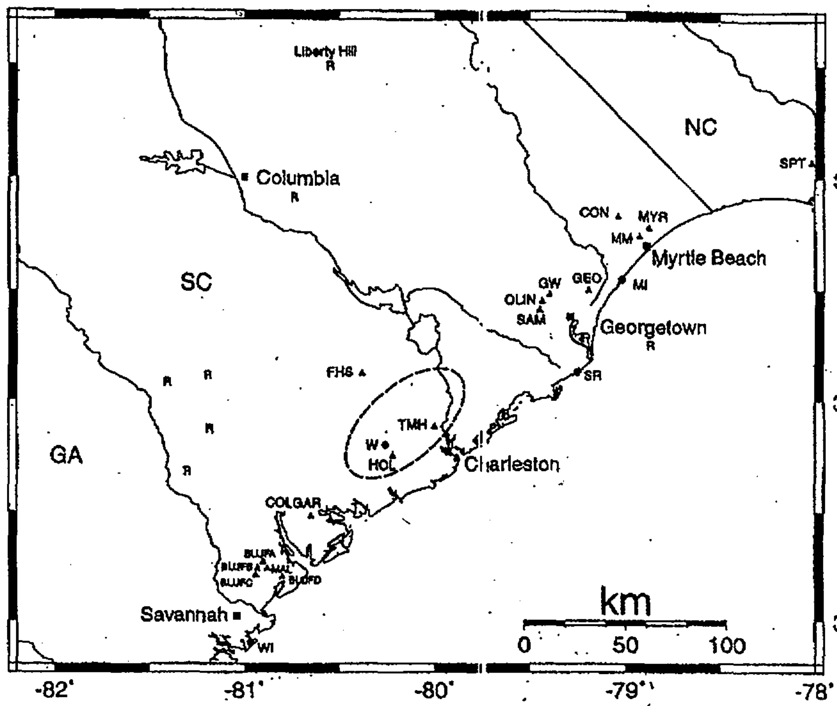

Figure 1. Dashed line encloses area of pronounced cratırlet activity associated with the 1886 earthquake [from *Dutton*, 1889]. Reports (R) of liquefaction features extend to Columbia and Georgetown [*Seeber and Armbruster*, 1981] and to Sand Hills near Liberty Hill [*Floyd*, 1969]. Liquefaction features associated with the 1886 earthquake were discovered at Warren's Crossroads (W) and at Bluffton (BLUF-A). Triangles show the location of paleoliquefaction sites in the North Carolina and South Carolina Coastal Plain from which datable material associated with prehistoric earthquakes was obtained. Abbreviations are as follows: Bluffton, BLUF; Colony Gardens, COLGAR; Conway, CON; Four Hole Swamp, FHS; Gapway, GW; Georgetown, GEO; Hollywood, HOL; Malpherous, MAL; Martin Marietta, MM; Myrtle Beach, MYR; Sampit, SAM; South Port, North Carolina, SPT; and Ten Mile Hill, TMH. Holocene ground water table data obtained from Murrell's Inlet (MI), Santee River Delta (SR), and Wilmington Island, Georgia (WI), are described in the text.

paleoliquefaction to other locations along the Atlantic seaboard [*Amick*, 1990; *Amick et al.*, 1990]. C. P. and K. Rajendran of the University of South Carolina discovered new sandblows near Bluffton and the Four Hole Swamp [*Rajendran and Talwani*, 1993; *Talwani et al.*, 1993], while *Schaeffer* [1996] discovered four at Gapway.

To use the liquefaction features for seismic hazard assessment, they must be dated. Abundant vegetation in the SCCP commonly makes it possible to collect organic material for radiocarbon dating. Most of the early dates came from a drainage ditch near Hollywood, South Carolina (*Talwani and Cox* [1985], *Weems et al.* [1986]; Table 1). Subsequently, *Weems et al.* [1988] and *Weems and Obermeier* [1990] obtained dates from sandblows covering an areal extent of ~25,000 km^2 in the SCCP. These data provided loose constraints on the ages and number of prehistoric earthquakes. To tighten the age constraints, *Amick et al.* [1990] obtained multiple dates at new sites discovered by them and of features originally discovered by *Obermeier et al.* [1990]. Additional dates at four locations in the Bluffton area were obtained by *Talwani et al.* [1993]. More recently, additional data were obtained in the Georgetown and Charleston areas, including the newly discovered sites at Gapway and Four Hole Swamp [*Schaeffer*, 1996] (Figure 1).

At each location one or more sandblows were encountered and as many as six datable samples were recovered from a single sandblow. In Tables 1 and 2, various locations of sandblows are referred to as "sites" (treating the four Bluffton locations as one site), and the sandblows are referred to as "features." The original names of sandblows assigned by the author(s) have been preserved. A total of 121 radiocarbon ages including 35 accelerator mass spectrometer (AMS) ages (Table 1) were obtained from 54 sandblows at 14 sites (Figure 1).

3. Methodology

The radiocarbon age of a sample can provide a minimum, contemporary, or maximum age estimate of the earthquake that caused the liquefaction, depending on the stratigraphic position of the sample and its cross-cutting relationship with elements of the sandblow. Radiocarbon dates reported by earlier workers had not been calibrated to account for fluctuations in atmospheric ^{14}C over time. In order to merge all of the age data collected by various workers the stratigraphic positions of the samples within the sandblows were reexamined, and conventional radiocarbon ages were recalibrated.

3.1 Dating Paleoliquefaction Features

Two methods discussed by *Amick et al.* [1990] were used to determine the age of the sandblows. The first method determines the relative age of the sandblow using weathering criteria, and the second determines its absolute age by radiometric dating of organic-rich samples. The relative age of a sandblow can usually be determined by examining the location of the sandblow and the thickness of the overlying soil profile, the

Table 1. Sources of Radiocarbon Dates[a]

Site	Number of Features	Data Source[b] 1	2	3	4	5	6	Total
SPT	1			1				1
CON	1			1				1
MYR	3			1	2			3
MM	1				2			2
GEO	3			1	6			7
GW	2						7	7
OLIN	2			1	5			6
SAM	9				11		10	21
FHS	1						1	1
TMH	6			1	10		2	13
HOL	8	7	11	2				20
COLGAR	1				2			2
MAL	1				6			6
BLUF	15			1	7	23		31

[a]The numbers of radiocarbon dates are shown under each data source. The sites are shown in Figure 1: Southport, North Carolina (SPT), Conway (CON), Myrtle Beach (MYR), Martin Marietta (MM), Georgetown (GEO), Gapway (GW), Olin, Sampit (SAM), Four Hole Swamp (FHS), Ten Mile Hill (TMH), Hollywood (HOL), Colony Gardens (COLGAR), Malpherous (MAL), and Bluffton (BLUF).

[b]References: 1, *Talwani and Cox* [1985]; 2, *Weems et al.* [1986]; 3, *Weems and Obermeier* [1990]; 4, *Amick et al.* [1990]; 5, *Talwani et al.* [1993]; 6, *Talwani et al.* [1999].

degree of staining, and the amount of weathering of the materials within the sandblow. In general, older sandblows have thicker overlying soil profiles, and the sediments in them are usually more heavily stained compared to the younger sandblows. Cross-cutting relationships can also be used to establish the relative age of one feature with respect to another.

The absolute age of a sandblow is obtained by ^{14}C dating of organic material recovered from within it. The absence of organics in borehole samples of sediments from below and near the sandblows (*Cox* [1984] and other unpublished data) allows us to conclude that all organics found in the sandblow came from above and were not a part of the ejected sand from below. Figure 2, modified from *Amick* [1990], illustrates how the stratigraphic position of samples in and around the sandblow can be used to infer its age and establish the minimum age and maximum age constraints. In Table 2 the sample location is described with respect to the stratigraphic setting in the sandblow. (For an excellent discussion of the morphology of a sandblow, see *Obermeier et al.* [1990].) "Contemporary" is used to describe the date of formation of the sandblow. The dates of pieces of leaves, bark, and wood that have been washed or blown into the sandblow shortly after its formation (item 1 in Figure 2) are interpreted as the best contemporary age estimates. For every sandblow, using the criteria described in Figure 2, we decided if the dates of organic samples were indicative of maximum, minimum, or contemporary age estimates of the ages of the earthquakes. These data gave broad ranges for the date of the earthquake. Then the contemporary ages were used in the calculations of dates of earthquake episodes (section 5).

3.2. Calibration of Radiocarbon Ages

In this study the ^{14}C dates determined from samples recovered during this study and previous studies were calibrated to obtain their calendar ages. The necessity for the calibration arises because the conventional ^{14}C date is determined assuming that the amount of atmospheric ^{14}C has remained constant over time. However, studies of tree ring samples have shown that the atmospheric ^{14}C has fluctuated over timescales of hundreds to thousands of years [*Geyh and Schleicher*, 1990]. In the calibration process the radiocarbon date is compared with the calibrated timescale curve. This was accomplished using the computer program CALIB v3.0.3c developed by *Stuiver and Reimer* [1993]. In the calibration program, intercept values of $\pm 1\sigma$ and $\pm 2\sigma$ are obtained for each calibrated age. When determining the interpreted age for the calibrated ^{14}C age dates, the 1σ range was used. In paleoseismological literature both 2σ ages [e.g., *Tuttle and Schweig*, 1996] and 1σ ages [e.g., *Bell et al.*, 1999] have been used to estimate the ages of prehistoric earthquakes. The 2σ ages have wider ranges, and those for two distinct events hundreds of years apart may overlap. Since the main objective of our analyses was to identify different prehistoric earthquakes and establish their ages, we chose a shorter range for correlation and used 1σ ages. The 1σ ranges provide a more rigorous test for correlation and are less likely to lead to spurious correlations.

4. Results

We examined the descriptions and figures and other relevant data for all the sandblows from which samples of organic material had been collected. Using the criteria given in section 3.1, each date was interpreted to be associated with the minimum, maximum, or contemporary age estimate of the causative earthquake. Each radiocarbon age date was calibrated (section 3.2). All the age relationships (Table 2) are the same as given by the original authors, except for those used by *Rajendran and Talwani* [1993] for Bluffton. Their field notes and figures were reanalyzed, and the revised age relationships are used in this study.

We discuss the data for the sites from northeast to southwest (Figure 1 and Table 2). Data from Sampit (Figure 3) are used to illustrate our approach. We discuss the age of the sandblow associated with each earthquake from the relative dates of the sample(s). For example, at some locations several samples were recovered from one sandblow, thus providing tighter age constraints (e.g., SAM-2A, SAM-2B, SAM-2C, and SAM-2D are four samples with contemporary ages from the sandblow Sampit Middle Right (SPMR) at the Sampit site).

4.1. Northern Sites

4.1.1. Southport, North Carolina, and Conway, South Carolina. These two are the northernmost sites (Figure 1) where datable material was recovered [*Weems et al.*, 1988; *Weems and Obermeier*, 1990]. Pieces of charcoal embedded deeply in intensely deformed soil profiles at Southport, North Carolina, and Conway yielded maximum ages of 9743 +167/−208 years B.P. and 6530 +204/−172 years B.P., respectively (Table 2).

4.1.2. Myrtle Beach. The Myrtle Beach site, ~10 km north of Myrtle Beach, South Carolina (MYR in Figure 1), is the northernmost site having a contemporary date of a sandblow in the SCCP. This site was investigated by *Amick et al.* [1990] and *Weems and Obermeier* [1990]. They identified three different sandblows at this site, and depending on the degree of staining and the thickness of the overlying soil profile, they were interpreted as not being associated with the 1886 Charleston earthquake. This interpretation is supported by ^{14}C age dates (Table 2). The calibrated dates suggest that at least two episodes of liquefaction occurred at this site. A stem recovered

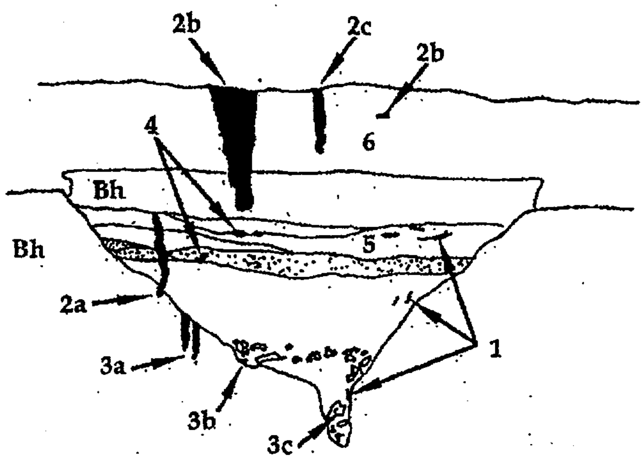

Figure 2. Schematic cross section of a sandblow crater that has intruded the soil profile and location of organic material used for radiocarbon dating. Bh is an organic-rich soil horizon. Clasts of Bh soil fall and are trapped with extruded clean sand within the crater. These are overlain by a bedded sequence of backfilled sand and organic material (item 5). The age of liquefaction episodes can be estimated by radiometric dating of organic materials that can be stratigraphically related to the liquefaction features. The most accurate age estimates are from radiometric dating of organic debris such as leaves, pine needles, bark, or small branches that were washed or blown into the liquefaction crater shortly after its formation (item 1). These are labeled "contemporary" ages. The ^{14}C ages of roots that have grown into the sandblow (item 2a) or the overlying soil profile (items 2b and 2c) provide minimum ages for the liquefaction episode. Minimum ages are also derived from forest-fire-derived charcoal from the shallow soil profile (item 6) overlying the feature. To be useful, this "new burn" charcoal must clearly be within the overlying soils that postdate feature formation. Maximum ages can be obtained from roots cut by the feature (item 3a), humate organic-rich soil (Bh) clasts that are isolated from contamination because of their depth in the feature (item 3b), or by organic material from soil clasts that predate liquefaction and collapsed into the deeper part of the crater during liquefaction (item 3c). Maximum age constraints can also be obtained by dating forest-fire-derived charcoal which was washed or blown into the crater after its formation (item 4). While wood from within the feature, especially the bedded sequence, can provide an accurate age constraint for the feature, charcoal is biologically inert, and before being washed into the bedded sequence, it can reside at or near the ground surface for hundreds or even thousands of years following a forest fire. Consequently, this type of sample only provides a maximum age constraint on the time of liquefaction. Modified from *Amick* [1990].

from the washed-in sand in the crater of feature 3 suggests that the earthquake causing liquefaction occurred ~1568 +310/−246 years B.P. (MYR-3, Table 2). Features 1 and 3 lie adjacent to each other with the same A horizon profile. The maximum age of an earthquake inferred from a humate clast in feature 1 overlaps the inferred contemporary age of MYR-3 and could possibly be associated with that episode, and not be representative of a younger one. A piece of "new burn" charcoal recovered from the overlying soil profile in feature 2 (MYR-2) suggests a liquefaction episode older than 5297 +353/−469 years B.P., and this is certainly different from the 1568 +310/−246 years B.P. liquefaction episode.

4.1.3. **Martin Marietta.** The Martin Marietta site (MM in Figure 1) is approximately 5 km south of the Myrtle Beach site. Here *Amick et al.* [1990] discovered three sandblows, but only one yielded organic material suitable for ^{14}C dating. One sample was a piece of tree bark from the lower portion of the central vent, which yielded a contemporary age for the liquefaction event. A sample of a humate-rich soil clast from the upper part of the sandblow, above the small clast zone, yielded a maximum age for the earthquake causing the liquefaction.

The calibrated dates indicate that at least one liquefaction episode occurred ~1809 +177/−257 years B.P. (MM-1A, Table 2). Field observations suggest that the tree bark associated with the contemporary age and the overlapping organic-rich soil clast are associated with the same episode.

4.1.4. **Georgetown.** The Georgetown site (GEO in Figure 1) is located approximately 35 km southwest of the Martin Marietta site and ~15 km north of the city of Georgetown. *Amick et al.* [1990] identified four sandblows at this site, all having similar staining and overlying soil profiles, which indicates that they developed about the same time. Features A, B, and C yielded four, two, and one organic samples, respectively, suitable for ^{14}C dating (Table 2). A root sample (GEO-2A) which had grown into feature B yielded a modern ^{14}C age, and it was interpreted as new growth and not used for age determination.

Interpreted calibrated ^{14}C age dates indicate two or possibly three episodes of liquefaction at this site. One episode occurred ~945 +223/−209 years B.P., on the basis of the contemporary date of a piece of wood recovered from within feature A (GEO-1D, Table 2). Field relations of the samples suggest that the overlapping minimum ages for GEO-1B and GEO-1C are associated with the same earthquake. Stratigraphic relationships indicate the occurrence of one or two other liquefaction episodes at this site. A minimum age constraint from sample GEO-2B indicates a liquefaction episode older than 2908 +337/−161 years B.P., and a maximum age constraint from sample GEO-3 indicates a liquefaction episode younger than 2739 +25/−257 years B.P. It is possible that GEO-3 represents the same episode indicated by GEO-1D.

4.1.5. **Gapway.** The Gapway site, discovered by *Schaeffer* [1996], is located ~60 km southwest of Myrtle Beach and approximately 20 km northwest of Georgetown (Figure 1). It contains four sandblows, two of which yielded datable samples (Figure 4). Four samples were recovered from Gapway A: A root that cuts the south boundary of the sandblow yielded a minimum ^{14}C age, (GW-1B, Table 2), and a second root that cuts the north boundary provided a minimum age (GW-1D). Two charcoal samples from the bedded sequence in the sandblow provided maximum ages (GW-1A and GW-1C). These ages indicate that this sandblow developed during a liquefaction episode that occurred between 1985 +68/−88 years B.P. (GW-1B) and 3623 +67/−146 years B.P. (GW-1C, Table 2).

Three samples from Gapway D indicate that one episode of liquefaction occurred at this site ~4985 +218/−113 years B.P. A twig from the bedded sequence yielded a contemporary ^{14}C age date (GW-2C), and a root which cut the north boundary of the feature yielded a minimum ^{14}C age which is considered a poor minimum age constraint. Small pieces of detrital charcoal from the bedded sequence of this sandblow were individually too small for age dating, so the pieces were combined to form a bulk detrital charcoal sample that yielded a maximum age of 4121 +88/−164 years B.P. (GW-2B). Normally, a maximum age would be older than the corresponding contemporary age.

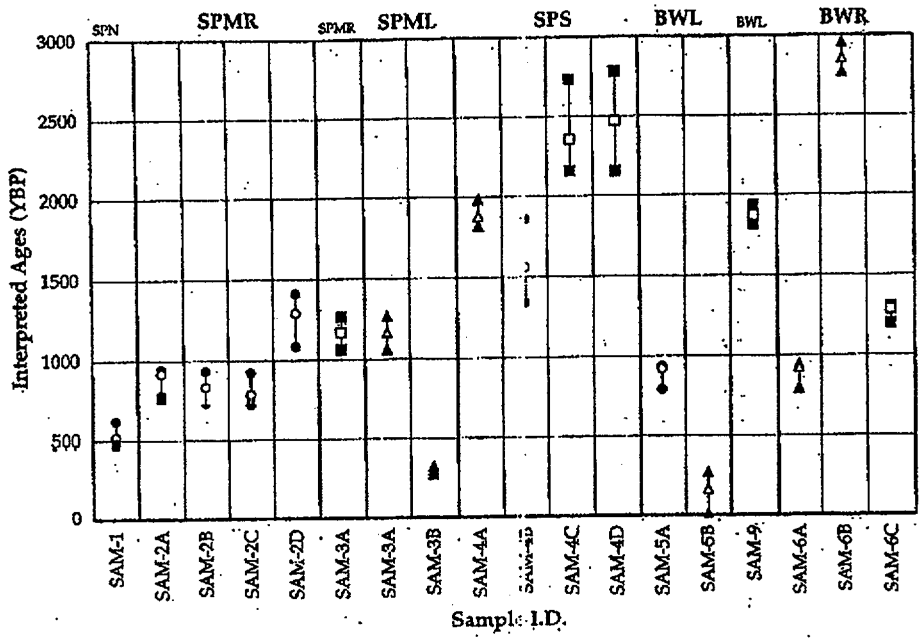

Figure 3. Plot of calibrated ages for Sampit site. Triangles, minimum ages; circles, contemporary ages; squares, maximum ages; short vertical lines, 1σ ranges. The features (Sampit North (SPN), Sampit Middle [illegible] Right (BWR)) are separated by bold vertical lines, and multiple samples from a single feature are designated by the letters A, B, ... (see also Table 2). Data from SAM-3A provide a maximum age constraint for SPMR and a minimum age constraint for SPML.

In this case the maximum age sample GW-2B is younger than the corresponding contemporary age sample GW-2C. Since this sandblow shows no signs of a second episode of liquefaction, and since sample GW-2B is a bulk soil sample, it could possibly have been contaminated with young material.

4.1.6. Olin. The Olin site is located ~50 km southwest of the Myrtle Beach site and approximately 20 km northwest of the city of Georgetown (Figure 1). *Amick et al.* [1990] discussed two sandblows identified by them and by *Weems and Obermeier* [1990] (Table 2). The degree of staining and the thickness of the overlying soil profile suggest that the sandblows at this site predated the 1886 Charleston earthquake. Five samples from feature A were dated by *Amick et al.* [1990], and one from feature B was dated by *Weems and Obermeier* [1990]. Analysis of the calibrated ^{14}C ages indicates that one liquefaction episode occurred ~1533 +452/−360 years B.P. This age was obtained from a sample of tree bark from within the sandblow, which yielded a contemporary ^{14}C age (OLIN-1C). Two tap root samples that cut the right boundary of the feature yielded bracketing minimum ^{14}C ages (OLIN-1A and OLIN-1B). Two charcoal samples from feature A yielded bracketing maximum ^{14}C age dates (OLIN-1E and OLIN-1D). Sample OLIN-2 indicates only the occurrence of a liquefaction event younger than 1511 +58/−157 years B.P., which does not distinguish its age from the age of the earthquake associated with feature A.

4.1.7. Sampit. *Amick et al.* [1990] and *Talwani et al.* [1999] studied six sandblows at the Sampit site, which is located ~1 km south of Olin, and analyzed 21 samples of organic material (Figures 1, 3, and 4 and Table 2). In the northern portion of this site a bark sample from the large clast zone in Sampit North (SPN; *Amick et al.* [1990]), yielded a contemporary ^{14}C age (SAM-1). Restudy of this site by *Talwani et al.* [1999] did not discover any additional datable samples. We interpret the contemporary calibrated age date to indicate that this sandblow was formed ~521 +102/−39 years B.P. (SAM-1).

Two sandblows in the middle part of the drainage ditch at Sampit were identified as Sampit Middle Right (SPMR) and Sampit Middle Left (SPML) by *Amick et al.* [1990]. Sampit Middle Right (SPMR) is located adjacent and to the south of SPML (Figure 4). They recovered four samples for ^{14}C dating: Two bark samples (SAM-2A and SAM-2B, Table 2) from the clast zone yielded contemporary ^{14}C age dates, and a bark sample (SAM-2C) from the bedded sequence in SPMR yielded a contemporary ^{14}C age date. *Amick et al.* [1990] identified a small crater-shaped sandblow within the main one, and on the basis of staining, they interpreted the smaller sandblow to have formed about the same time as the main feature. A bark sample (SAM-2D) from the smaller sandblow yielded a contemporary age.

The four contemporary ages define the approximate time that SPMR developed. The 1σ age range of SAM-2D does not overlap those of the other three samples, possibly because SAM-2D was recovered from a smaller feature that was located within the main sandblow and that probably predates it.

Sampit Middle Left (SPML) is adjacent to and north of SPMR (Figure 4). A sample of a root that had grown into the feature was analyzed by *Amick et al.* [1990] and yielded a minimum ^{14}C age date (SAM-3A). *Amick et al.* [1990] also found evidence of a younger, small sand dike that had intruded SPML and cut the root (SAM-3A). This indicates the root was in place prior to the sand dike intrusion. The degree of staining of the sand dike and SPMR are similar, which was interpreted as showing that both developed about the same time. Therefore this sample represents not only a minimum age for SPML but also a maximum age for SPMR. *Talwani et al.* [1999]

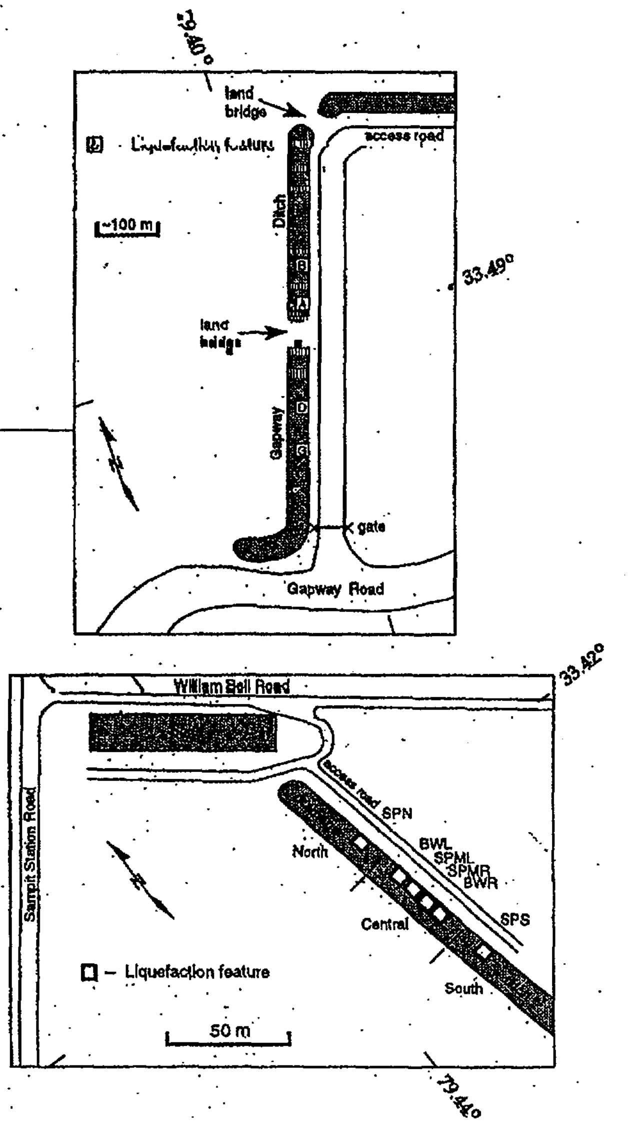

Figure 4. Schematic maps of the (top) Gapway and (bottom) Sampit sites showing locations of features in the drainage ditches.

recovered a sample of wood from the top of SPML, which is believed to have been deposited in the crater sometime after it formed. This sample provides a minimum ^{14}C age (SAM-3B). The clear cross-cutting relations that were observed between BWL (discussed later) and SPML were interpreted to show that SPML is older than SAM-5A. The young age of SAM-3B suggests that it was derived from spoil that fell onto the surface of the sandblow and therefore does not reflect an age constraint for it. The minimum age SPML indicates that it developed during a liquefaction episode older than 1165 +100/−105 years B.P. (SAM-3A). Since the upper portion of the south boundary of BWL (described below) cuts the upper portion of the north boundary of SPML, this cross-cutting relationship indicates that SPML existed prior to the formation of BWL.

Sampit South (SPS) is in the southern portion of the Sampit site (Figure 4). *Amick et al.* [1990] recovered four samples from it. Two charcoal samples (SAM-4C and SAM-4D) from the bedded sequence yielded maximum ages, a carbonized wood sample from the bedded sequence (SAM-4B) yielded a contemporary ^{14}C age date, and a root sample that had grown into SPS (SAM-4A) yielded a minimum age. Field observations of the location of this sample (SAM-4A) suggest that it is associated with the same episode. Analysis of the calibrated age dates indicate that SPS developed during a liquefaction episode that occurred around 1561 +302/−221 years B.P. (SAM-4B, Figure 3). This episode is bracketed by two maximum ages, SAM-4C and SAM-4D.

In a later study, *Schaeffer* [1996] discovered two more sand blows in the central portion of the Sampit site (Big White Left and Big White Right). Big White Left (BWL) is located north of and adjacent to SPML. *Schaeffer* [1996] recovered three samples for ^{14}C dating. A bark sample yielded a contemporary ^{14}C age (SAM-5A), a root (SAM-5B) recovered from BWL yielded a minimum ^{14}C age, and a third sample was a piece of wood from stump H2 (SAM-9), around which BWL developed. Since the stump predates development of this feature, the wood sample is a maximum age constraint for BWL (SAM-9).

Big White Right (BWR) is located ~3 m to the south of SPMR and yielded three datable samples. A root that had grown into BWR yielded a minimum ^{14}C age (SAM-6A), a second root recovered from another part of this feature yielded a minimum ^{14}C age (SAM-6B), and charcoal recovered from within it yielded a maximum ^{14}C age date (SAM-6C). Upon inspection of the calibrated ages from BWR it was found that the minimum age sample, SAM-6B, has an older age than the maximum age sample, SAM-6C. The exact cause of this discrepancy is not known, but it is suspected that a labeling error occurred either at the testing laboratory or during the field preparation of these two samples. Since a reliable maximum age is not available, the analysis of the calibrated ages indicates that BWL is older than 925 +21/−131 years B.P. (SAM-6A, Table 2).

Summarizing, dates of the paleoliquefaction features and their cross-cutting relations at Sampit suggest at least three episodes of earthquake activity (Figure 3). SAM-1, collected from the northern part of the drainage ditch, is associated with an earthquake that occurred around 500 years B.P. The four samples from SPMR (SAM-2A to SAM-2D) and one from BWL (SAM-5A) and bracketing ages at BWR (SAM-6A and SAM-6C) argue for an event that occurred ~1000 years B.P. The cross-cutting relationship of BWL with SPML suggests that SPML (SAM-3) is associated with an earthquake older than BWL (SAM-5) and SPMR (SAM-2). The minimum age of SPML (SAM-3A) and the maximum age of BWL (SAM-9) could be associated with the earthquake that yielded a contemporary age at SPS (SAM-4B), 1561 +302/−221 years B.P.

4.2. An Inland Sandblow

The Four Hole Swamp (FHS) site is located approximately 25 km northwest of Summerville (Figure 1) near the intersection of highways 78 and 178. This site is situated on a Pleistocene age beach ridge composed of clean, fine-to-medium-grained sand. A sandblow at this site was discovered by C. P. Rajendran (unpublished data, 1993). A bark sample collected from within it (FHS-1, Table 2) yielded a contemporary age of 1659 +70/−107 years B.P., which was taken to be the age of the paleoliquefaction event [*Talwani et al.*, 1999]. *Schaeffer* [1996] found no new datable samples.

4.3. Central (Charleston) Sites

4.3.1. Ten Mile Hill. In the Charleston area many sandblows formed near Ten Mile Hill in 1886 (Figure 1), but because of extensive urbanization and thick vegetation, direct evidence of the sandblows is obscured. *Amick et al.* [1990] discovered four sandblows in a drainage ditch ~1.6 km north of the Charleston Air Force Base (CAFB). Another feature near CAFB was studied by *Weems and Obermeier* [1990]. During a recent study by *Talwani et al.* [1999], anomalous sand was encountered in a hole drilled for standard penetration tests ~0.8 km north of the CAFB. A shallow trench (~1.5 m deep) at this location provided two datable samples.

Four contemporary ages for features A and C of *Amick et al.* [1990] and Airport (ARP) of *Weems and Obermeier* [1990] (TMH-1A, TMH-1B, TMH-3, and TMH-5, Table 2) all suggest that an episode of liquefaction occurred between 3400 and 3700 years B.P. TMH-1D gave an anomalously younger contemporary age, whereas TMH-4A and TMH-4B bracket an older event between ~5400 and 6600 years B.P., and TMH-2A and TMH-2B provide minimum ages.

TMH-6A, collected from the shallow trench, consisted of pieces of wood sieved from clayey sand and is possibly contaminated. It gave a contemporary (?) age of 1299 +47/−21 years B.P. (TMH-6A). The second sample consisted of pieces of charcoal sieved from a few pounds of silty clay, yielded an age of 4038 +46/−109 years B.P. (TMH-6B), and is interpreted as a maximum age. It possibly represents the age of the enclosing clay layer.

4.3.2. Hollywood. Several sandblows in a drainage ditch just north of Hollywood (HOL in Figure 1) and located ~30 km to the west of Charleston provided samples at seven locations (*Talwani and Cox* [1985], *Weems et al.* [1986, 1988], and *Weems and Obermeier* [1990]; Table 2). Contemporary ages were obtained from HOL-6A with a strong minimum age constraint for an earthquake at ~600 years B.P. (HOL-6B). Four samples from site 2 (HOL-7A to HOL-7D) and one from Hollywood XIV (HOL-8) gave contemporary age dates for an earthquake between ~1000 and 1200 years B.P. The other sandblows provided broad minimum or maximum age constraints. For example, HOL-1A to HOL-1E support the occurrence of one or more earthquakes between ~1500 and 4000 years B.P. At another site the dates obtained for HOL-2A and HOL-2B suggest an earthquake that occurred before 3200 years B.P.

At the Hollywood XIII site the ages of samples HOL-3A and HOL-3B argue for an earthquake between ~4700 and 7900 years B.P.; elsewhere, the sample HOL-4 did not provide any age constraint. HOL-5A and HOL-5B provide weak constraints for an event (events) between 1700 and 4768 years B.P.

Thus the data from Hollywood suggest at least four prehistoric earthquakes. Well-constrained ages identify an earthquake between ~500 and 600 years B.P. (HOL-6A and HOL-6B) and another one between ~1000 and 1200 years B.P. (HOL-7A to HOL-7D and HOL-8). Weak constraints suggest an event between ~1500 and 4100 years B.P. (HOL-1A and HOL-1E) and between ~1700 and 4800 years B.P. (HOL-5B and HOL-5A). Finally, an earthquake with poorly constrained age may have occurred between ~4700 and 7900 years B.P. (HOL-3B and HOL-3A).

4.4. Southern Sites

Samples from six sites south of Charleston (Figure 1) provide ages of liquefaction episodes similar to those near Charleston and the northern sites. From north to south they are Colony Gardens (COLGAR), Malpherous (MAL), and Bluffton A–D (Figure 1).

4.4.1. Colony Gardens. Colony Gardens (COLGAR in Figure 1) is the closest of the southern liquefaction sites to Charleston. *Amick et al.* [1990] identified several sandblows, the largest approximately 3 m in width, comparable to some of the larger features discovered at Ten Mile Hill. A piece of wood recovered from a unit of interbedded sand and organics gave a contemporary age of 958 +100/−34 years B.P. (Table 2). A second piece of wood recovered from a soil clast provided a tight maximum age constraint of 1263 +31/−124 years B.P. Thus the data from Colony Gardens support a prehistoric earthquake occurring around 1000 years B.P.

4.4.2. Malpherous. Six samples from one heavily stained sandblow provided age constraints, but no contemporary age date [*Amick et al.*, 1990] at Malpherous (MAL in Figure 1). The inferred age of one earthquake, between ~5300 and 6300 years B.P., is constrained by a large root that had grown into the sandblow and provided a minimum age constraint (MAL-1A) (Table 2) and a small charcoal sample from within a soil clast that had collapsed into the same feature, which provided a maximum age constraint (MAL-1B). Three splits of a humate clast gave redundant maximum ages (MAL-1D to MAL-1F). Younger roots from MAL-1C provided minimum age constraints that were not useful.

4.4.3. Bluffton. Four liquefaction sites near Bluffton were named BLUF-A to BLUF-D. BLUF-A and BLUF-B were originally discovered by *Obermeier et al.* [1987]. *Amick et al.* [1990] reinvestigated BLUF-A and BLUF-B and discovered BLUF-C. *Talwani et al.* [1993] reinvestigated BLUF-A to BLUF-C and discovered BLUF-D, ~6 km east of the earlier sites. Thus, for the various sites, samples analyzed by one or more investigators provide redundancy and better age constraints. The age relation used by *Rajendran and Talwani* [1993] were reanalyzed using the criteria in section 3.1, and the revised relationships are given in Table 2.

Amick et al. [1990] dated organic material in four sandblows at site BLUF-A (features A-1, A-2, A-3, and A-4) and, for the first three, obtained contemporary ages corresponding to the 1886 Charleston earthquake (Table 2). At the fourth location (feature A-4) they obtained a minimum calibrated age of 301 +157/−301 years B.P. (BLUF-4A) and a contemporary calibrated age of 598 +741/−93 years B.P. (BLUF-4B). These ages are close to the contemporary age of *Weems and Obermeier* [1990] for the same feature, 547 +103/−36 years B.P. (BLUF-4C). *Talwani et al.* [1993] discovered seven sandblows at BLUF-A, four of which provided no datable samples and one of which (identified in Table 2 as BLUF-4E was the same as that studied earlier by *Weems and Obermeier* [1990] and *Amick et al.* [1990] (feature A-4). In feature A-4, *Talwani et al.* [1993] also found a new burn charcoal in the sands overlying the feature that yielded a minimum calibrated age of 376 +132/−87 years B.P. (BLUF-4D). A piece of charcoal within the sandblow yielded a maximum radiocarbon age of 656 +471/−105 years B.P. (BLUF-4E). These dates further constrain the ages obtained by *Amick et al.* [1990] (BLUF-4A and BLUF-4B) and *Weems and Obermeier* [1990] (BLUF-4C). Thus, at BLUF-A, feature A-4 yielded contemporary ages of 550–600 years B.P. (BLUF-4B and BLUF-4C), and these ages were bracketed by minimum ages of 301 years B.P. (BLUF-4A) and 376 years B.P. (BLUF-4D) and a maximum age of 656 years B.P. (BLUF-4E). Roots in clasts in another sandblow at

BLUF-A, feature A-6, provided a minimum age of 1213 +85/−148 years B.P. (BLUF-6A), and an aggregate of charcoals from two locations within the sandblow gave a maximum age of 1072 +191/−103 years B.P. (BLUF-6B). Because of the aggregation the age of BLUF-6B does not provide a tight constraint. The age of the sample from BLUF-6A suggests an earthquake older than ~1200 years B.P. At feature A-7 a "fresh" piece of charcoal within the sandblow yielded a probable contemporary age of 532 +108/−36 years B.P. (BLUF-7).

At BLUF-B, *Talwani et al.* [1993] investigated five sandblows; four yielded datable samples. Sandblow feature B-9 had been earlier investigated by *Amick et al.* [1990] and was identified as their site BD. In this study, that sandblow is identified as feature B-5 and provided four calibrated ages. The two studies provided two minimum ages (BLUF-5B and BLUF-5D) and two maximum ages (BLUF-5A and BLUF-5C), bracketing the age of the liquefaction episode between ~1780 and 2140 years B.P. One of the three organic samples at feature B-8 yielded a modern date. Of the other two, a piece of bark in the bedding sequence yielded a contemporary age of 527 +22/−20 years B.P. (BLUF-8B) whereas a new burn piece of charcoal (BLUF-8A) gave a minimum radiocarbon age of 121 +190/−121 years B.P. Charcoal in feature B-9 gave a maximum age of 1327 +89/−49 years B.P. At site B-10, charcoal in the soil profile cut by the sandblow (BLUF-10A) gave a maximum age of 1874 +123/−157 years B.P., whereas charcoal within it (BLUF-10B) gave a maximum age of 697 +91/−42 years B.P. Summarizing, at BLUF-B we have evidence of two or possibly three prehistoric earthquakes: an earthquake that occurred between ~500 and 600 years B.P. (BLUF-8B, and bracketing maximum age, BLUF-10B), loose constraint for an event younger than ~1300 years B.P. (BLUF-9), and an older earthquake between ~1800 and 2150 years B.P. (BLUF-5B and BLUF-5A).

At BLUF-C, wood from feature C-11 yielded a contemporary age of 532 +110/−40 years B.P. (BLUF-11), and charcoal in the sandblows and a new burn charcoal in the redeveloped soil profile in feature C-12 provided bracketing ages between ~2300 and 700 years B.P. (BLUF-12A and BLUF-12B). These loosely constrain the timing of one or more earthquakes.

At BLUF-D, four sandblows were discovered by *Talwani et al.* [1993], from which a piece of charcoal within the bedding sequence provided a maximum age of 4190 +224/−251 years B.P. (BLUF-13), and no datable material was obtained from the second feature. Two radiocarbon samples from feature D-14 indicate that an earthquake occurred ~3400 years B.P. on the basis of a contemporary date of a piece of wood from within the bedding sequence (BLUF-14A) and of a piece of charcoal in a clast in the sandblow (BLUF-14B).

Five samples were recovered from feature D-15. Three charcoal samples (BLUF-15B, BLUF-15D, and BLUF-15E) provide maximum ages ranging from ~4264 to 4766 years B.P. BLUF-15A was a sample from a root in the feature and provided a minimum age of ~1400 years B.P. BLUF-15C consisted of a sample of brownish charcoal or wood in the sandblow. It provided a contemporary age of 3354 +115/−188 years B.P. Thus data from all three sandblows at BLUF-D (features D-13 to D-15) suggest the occurrence of an earthquake ~3400 years B.P. Next all the calibrated ages given in Table 2 were analyzed for recurrence rates and seismogenic sources (section 5).

5. Dates and Magnitudes of Prehistoric Earthquakes

To determine the dates and estimate the magnitudes of prehistoric earthquakes, we examined the calibrated ages and stratigraphic positions of samples from the various sandblows throughout the Coastal Plain of South Carolina. For each sandblow we obtained an estimate of its age from the radiocarbon data and stratigraphic setting. When contemporary ages were available, they were interpreted to be the age of the causative paleoearthquake. Ages of other sandblows were based on maximum and minimum age constraints discussed in section 4. Once all the age data for all the sandblows were in hand, they were compared with each other and used to obtain the dates of earthquake episodes that caused them. Contemporary ages and corroborative age constraints, where available, were binned together according to the following criteria. Overlapping 1σ ranges of contemporary dates were interpreted to indicate a single earthquake episode. The estimated age of the episode is calculated from the weighted averages of the overlapping contemporary ages. An absence of overlapping 2σ ranges of contemporary dates was interpreted to indicate different earthquake episodes. The maximum and minimum ages were used to provide constraints. If a particular sandblow had both maximum and minimum age ranges that overlapped the range of contemporary 1σ ages, they are referred to as tight-bracketing age constraints. If the range of 1σ maximum and minimum ages did not overlap the range of 1σ contemporary ages, they are referred to as loose-bracketing age constraints. If only a maximum or a minimum age was available for a particular sandblow, it was referred to as a tight or loose age constraint depending on if the corresponding range of 1σ ages overlapped the contemporary age ranges or not.

We use earthquake episodes because it is not possible to determine if a specific liquefaction feature is associated with only one mainshock or with the mainshock and its aftershocks. The analysis identified seven prehistoric episodes (episodes A–G), which are discussed below. The dates of formation of sandblows at various sites were compared with each other to infer the date of the earthquake episode. The data for each episode are presented in Figures 5a–5g, wherein samples from a site are identified in accordance with Table 2. For each episode the contemporary dates and tight-bracketing constraints are plotted once and were used to define its age. In some cases, loose-bracketing constraints and the loose constraints could apply to more than one episode, and they are included in figures for more than one episode. For example, the ages of BLUF-12A and BLUF-12B provide loose constraints for the dates of episodes B, C, and D. Here they are included with data for episode D (Figure 5d). However, only locations that provided contemporary or tight-bracketing dates for each episode are shown in Figure 6.

Various empirical methods have been suggested to estimate the magnitude of an earthquake from paleoliquefaction data [see, e.g., *Ambraseys*, 1988; *Tuttle*, 1994; *Obermeier and Pond*, 1999]. We chose a simple method that is probably more applicable to the SCCP and compared our results with the empirical method of *Ambraseys* [1988].

The areal extent of liquefaction features associated with a particular prehistoric episode was compared with the areal distribution of sandblows associated with the 1886 earthquake to estimate the size of the prehistoric earthquake. For contemporary sandblows occurring in the northern, central, and south-

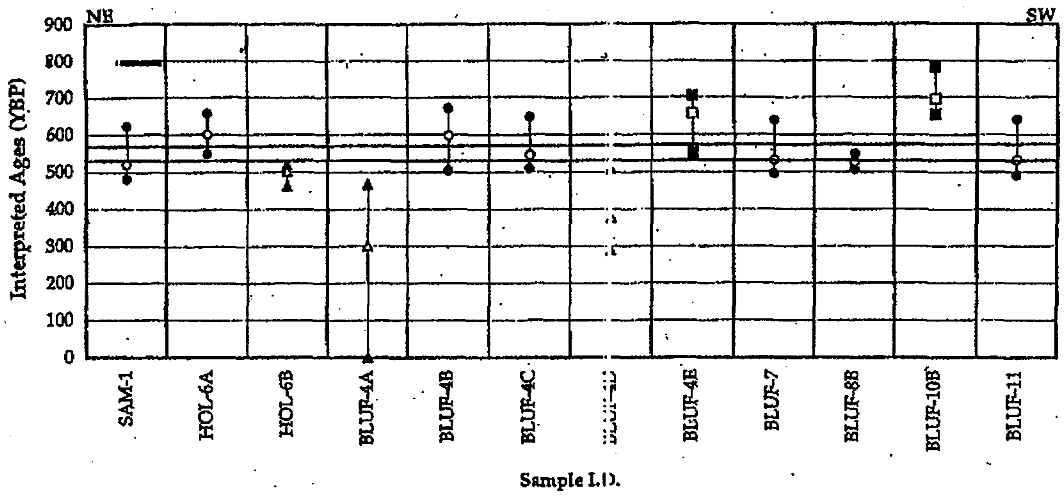

Figure 5a. Age data used to obtain the age of episode A (546 ± 17 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. BLUF-4A to BLUF-4D and BLUF-7; BLUF-8B and BLUF-10B; and BLUF-11 are samples from BLUF-A, BLUF-B, and BLUF-C, respectively. The thick horizontal lines bracket the interpreted age of the episode.

ern parts of the SCCP the assigned magnitude is M 7+ (comparable with the 1886 earthquake). Smaller magnitudes were assigned to episodes with smaller areal distribution of sandblows. *Obermeier et al.* [1990] argue that the sandblows discovered by them were caused by earthquakes stronger than m_b 5.5 (based on their estimate of the threshold magnitude for liquefaction in the SCCP). When we encountered liquefaction features of a particular age at more than one site, but with smaller areal extent than the 1886 Charleston earthquake, we have assigned a minimum magnitude M 6.0.

On the basis of over 100 data points, *Ambraseys* [1988] found that moment magnitude M for any earthquake was related to the maximum epicentral distance R_e, measured from the adopted epicenter to the most distant site where there was clear evidence of liquefaction-induced ground failure. He found that the equation

$$M = -0.31 + 2.65 \times 10^{-8} R_e + 0.99(\log R_e),$$

where R_e (in centimeters), represented the upper limit for R_e as a function of M.

The 1886 Charleston earthquake caused widespread liquefaction, and sandblows formed hundreds of kilometers from Charleston [*Dutton*, 1889; *Seeber and Armbruster*, 1981]. Besides the meizoseismal area, liquefaction features described as "sinkholes" were found at four locations over a hundred kilometers west of Charleston, along the coast near Georgetown, and inland near Columbia [*Dutton*, 1889; *Seeber and Armbruster*, 1981] and in Sand Hills near Liberty Hill [*Floyd*, 1992] (Figure 1). After the discovery of a sandblow associated with the 1886 earthquake near Warren's Crossroads (*Cox* [1984]; Figure 1), intensive search over the SCCP for other 1886 sandblows was not very successful. Only three other sandblows associated with the 1886 earthquake were discovered near Bluffton (BLUF-1, BLUF-2, and BLUF-3, Table 2). Comparing the felt area and the areal extent of various intensity values

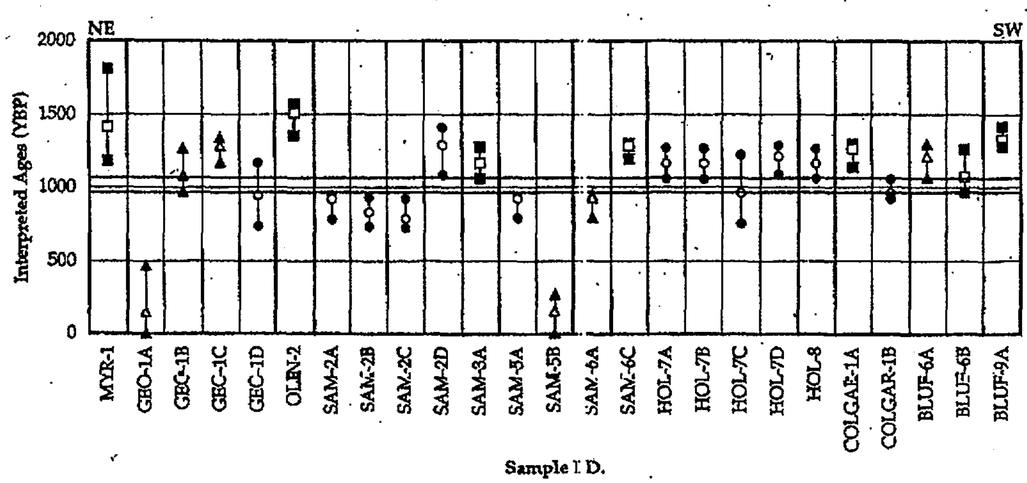

Figure 5b. Age data used to obtain the age of episode B (1021 ± 30 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. BLUF-6A, BLUF-6B, and BLUF-9A are samples from BLUF-A and BLUF-B, respectively. The thick horizontal lines bracket the interpreted age of the episode.

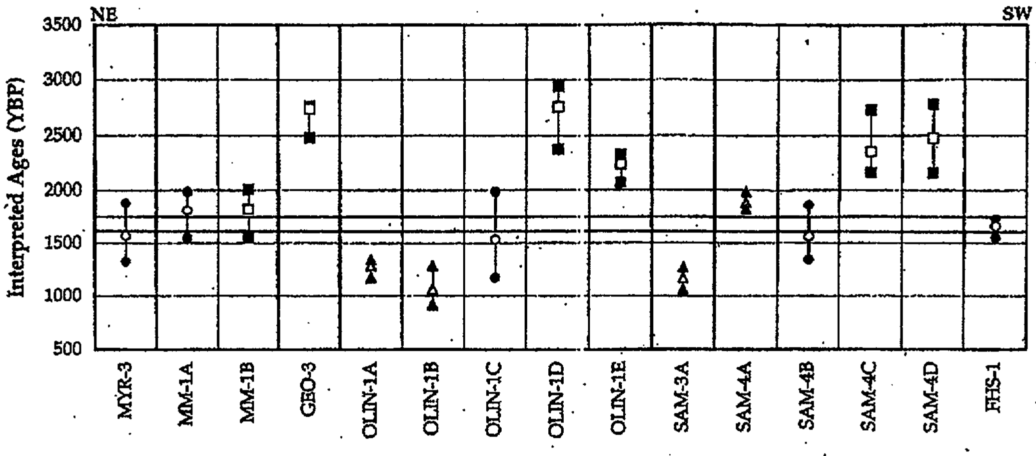

Figure 5c. Age data used to obtain the age of episode C (1648 ± 74 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6.

for the 1886 Charleston earthquake with those of other earthquakes in stable continental regions, *Johnston* [1996] assigned it a magnitude M 7.3 ± 0.26. Assuming that the current seismicity defines the source of the 1886 Charleston earthquake and considering reports of liquefaction near Columbia (160 km) and Liberty Hill (180 km), application of *Ambraseys'* [1988] formula yields estimates of 7.3 and 7.4, respectively, values comparable to *Johnston*'s [1996] estimates. The estimated magnitudes and dates of prehistoric earthquakes that caused liquefaction were combined to estimate the recurrence times of large earthquakes in the South Carolina Coastal Plain.

5.1. Episode A

Seven contemporary ages between ~500 and 600 years B.P. with overlapping 1σ ranges were obtained from samples at Sampit in the north (SAM-1), Hollywood near Charleston (HOL-6A), and BLUF-A (BLUF-4B, BLUF-4C, and BLUF-7), BLUF-B (BLUF-8B), and BLUF-C (BLUF-11) in the south (Figures 5a and 6). The weighted average of the seven dates (including uncertainties) is 546 ± 17 years B.P., which is the age we assign episode A. Tight-bracketing constraint to this age was obtained from three samples from BLUF-B (BLUF-4A (minimum), BLUF-4D (minimum), and BLUF-4E (maximum)). Tight constraints were also obtained from Hollywood (HOL-6B (minimum)) and BLUF-B (BLUF-10B (maximum)). Loose constraints were obtained from Myrtle Beach and Olin (MYR-1 and OLIN-2). As contemporary ages were obtained from locations in the north, the middle, and the south (Figure 6) we interpret the earthquake(s) associated with episode A to be at least as large as the 1886 episode and centered near Charleston and assign it a magnitude M 7+. On the basis of the epicentral distance (110 km) to the most distant sandblow (BLUF-C, Figure 6a), *Ambraseys'* [1988] formula gives M 7.0.

5.2. Episode B

Twelve contemporary ages between ~900 and 1200 years B.P. with overlapping 1σ ranges were obtained from Georgetown (GEO-1D), Sampit (SAM-2A to SAM-2D and SAM-5A) in the northern part of the SCCP, Hollywood (HOL-7A to

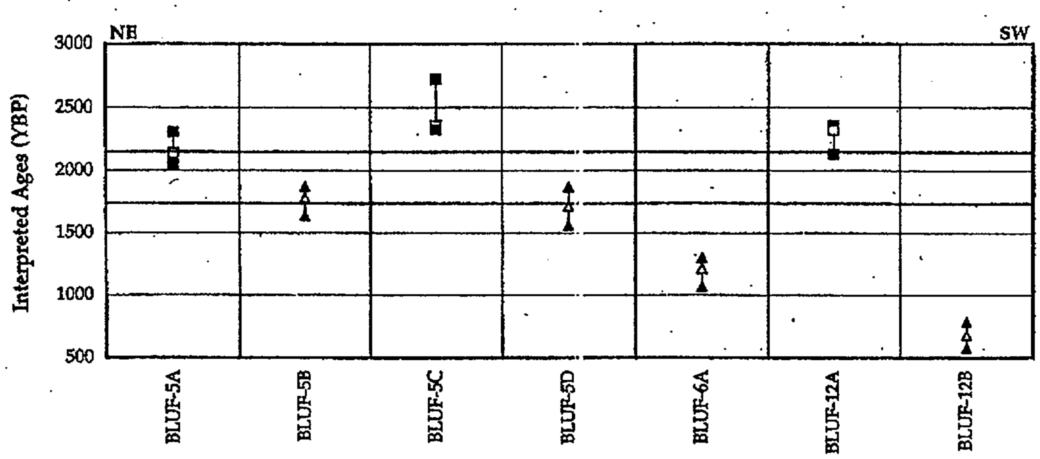

Figure 5d. Age data used to obtain the age of episode D (1754–2177 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. BLUF-5A to BLUF-5D and BLUF-6A; and BLUF-12A, and BLUF-12B are samples from BLUF-B and BLUF-C, respectively. The thick horizontal lines bracket the interpreted age of the episode.

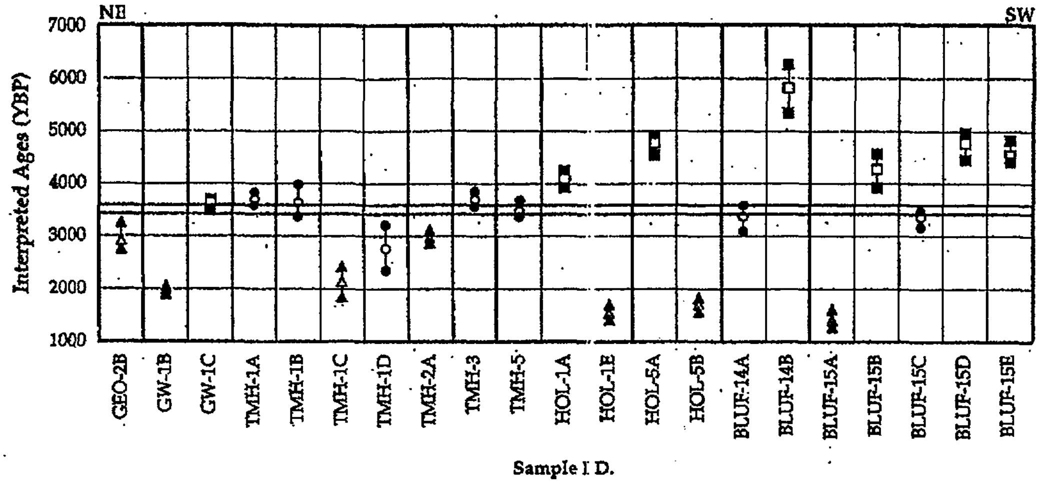

Figure 5e. Age data used to obtain the age of episode E (3548 ± 66 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. BLUF-14A, BLUF-14B, and BLUF-15A to BLUF-15E are samples from BLUF-D. The thick horizontal lines bracket the interpreted age of the episode.

HOL-7D and HOL-8) near Charleston, and Colony Gardens (COLGAR-1B) in the southern part of SCCP (Figures 5b and 6). The weighted average of the 12 dates was 1021 ± 30 years B.P., which is the age we assign to episode B. The interpreted age of episode B is tightly constrained by bracketing ages at Georgetown (GEO-1B and GEO-1C), Sampit (SAM-6A and SAM-6C), Colony Gardens (COLGAR-1A), and BLUF-A (BLUF-6A and 6B), by another three maximum ages (Figures 5b and 6), and, loosely, by one maximum and two minimum ages.

In view of the occurrence of contemporary ages from locations in the northern, the middle, and the southern sites along the coast (Figure 6) we interpret episode B to be as large as the Charleston 1886 episode and to be dated 1021 ± 30 years B.P. and also located near Charleston and assign it a magnitude M 7+. Application of *Ambraseys*' [1988] formula, with an epicentral distance of 110 km to Georgetown (GEO in Figure 6b), gives M 7.0.

5.3. Episode C

Five contemporary ages between ~1500 and 1800 years B.P. with overlapping 1σ ranges were obtained from samples at Myrtle Beach (MYR-3), Martin Marietta (MM-1A), Olin (OLIN-1C), and Sampit (SAM-4B) sites in the north and from Four Hole Swamp (FHS-1), ~50 km northwest of the Charleston area (Figures 5c and 6). The weighted average of the five contemporary dates was 1648 ± 74 years B.P., which is the age we assign to episode C. The interpreted age of episode C is tightly constrained by bracketing ages at Olin (OLIN-1A, OLIN-1B, and OLIN-1E) and Sampit (SAM-4A, SAM-4C, and SAM-4D) and by a maximum value at Martin Marietta (MM-1B) and a minimum value at Sampit (SAM-3A). In view of the absence of any contemporary or tightly bracketing age near Charleston, or at southern sites, we interpret episode C to be associated with a seismic source in the north. Because of the smaller areal extent of sandblows associated with episode C

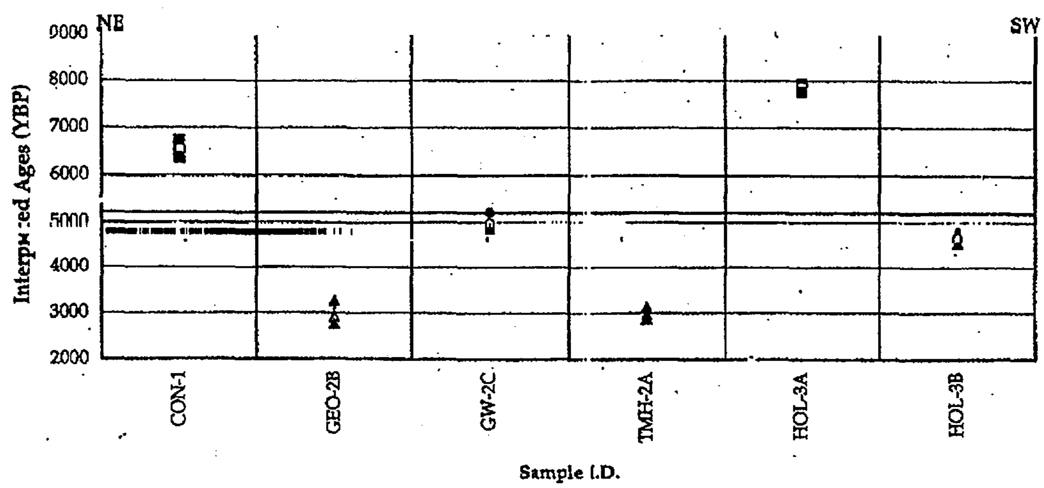

Figure 5f. Age data used to obtain the age of episode F (5038 ± 166 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. The thick horizontal lines bracket the interpreted age of the episode.

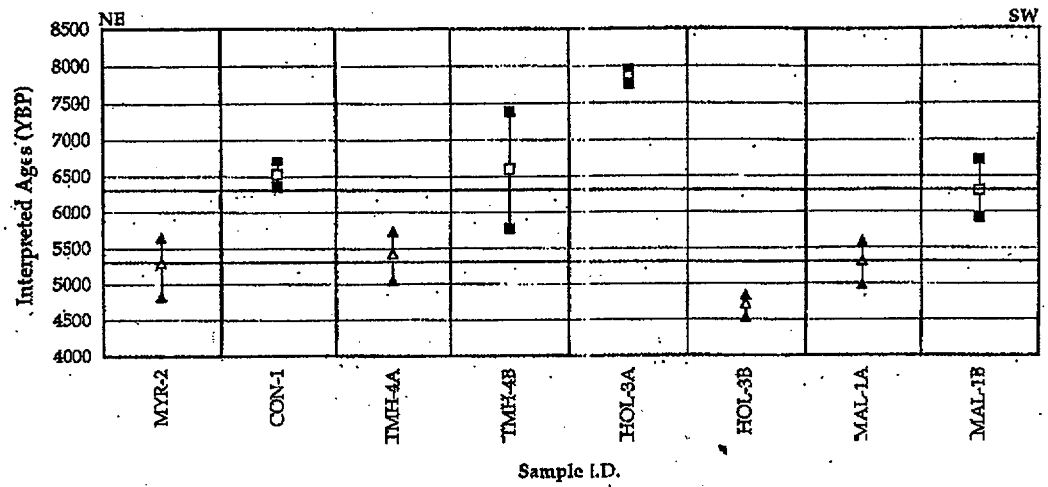

Figure 5g. Age data used to obtain the age of episode G (5300–6300 years B.P.). Symbols are defined in Figure 3. Locations of samples providing contemporary ages and tight-bracketing ages are shown in Figure 6. The thick horizontal lines bracket the interpreted age of the episode.

(Figure 6) we interpret the magnitude to be smaller than that of the 1886 episode and assign it a magnitude of M 6.0. Assuming a northern source midway between the Sampit and Myrtle Beach sites (SAM and MYR in Figure 6), an epicentral distance of 35 km, suggests M 6.3 using *Ambraseys'* [1988] formula. If we estimate the source to be midway between Four Hole Swamp and Myrtle Beach (FHS and MYR), we get M 6.8.

5.4. Episode D

We do not have convincing evidence for episode D lying between ~1700 and 2200 years B.P. Evidence of episode D is inferred primarily from tight-bracketing ages from four samples from BLUF-B (BLUF-5A to BLUF-5D), a maximum value at BLUF-C (BLUF-12A), and a minimum value at BLUF-A (BLUF-6A) (Figures 5d and 6). Because evidence of episode D is limited to the southern sites (Figure 6), we interpret it to be associated with a southern source near Bluffton, and because of the limited areal extent of the sandblows we assign it a magnitude M 6.0. The age is inferred to lie between ~1754 and 2177 years B.P. Application of *Ambraseys'* [1988] formula, and assuming an epicentral distance of 10 km yields M 5.7.

Although no evidence of episode C or episode D was found near Charleston, we cannot rule out the alternative scenario that episode C (the evidence for which was found at northern sites and near Four Hole Swamp) (Figure 6) and episode D (the evidence for which was found near Bluffton) (Figure 6) were associated with one (or two) larger earthquake(s), centered near Charleston. If the age of episode C is 1648 ± 74 years B.P. and the age of episode D is 1966 ± 212 years B.P., then they are statistically different at 1σ level but the same at 2σ level. Alternatively, if we assume that they were in fact associated with a single large episode C′, the weighted mean of their ages is 1683 ± 70 years B.P. Because episode C′ incorporates ages of sandblows to the north (near Georgetown), the northwest (near Four Hole Swamp), and the south (near Bluffton) of Charleston, we ascribe the episode to the Charleston source. We attribute the absence of contemporary sandblows near Charleston to their being obliterated by successive earthquakes or to our having just not found them. We assign episode C′ a magnitude M 7+ on the basis of the spatial extent of contemporary sandblows. Assuming the epicenter to lie near Charleston, and epicentral distance to MYR, using *Ambraseys'* [1988] formula suggests M 7.2. We retain the episodes C and D scenario and the episode C′ scenario as likely interpretations of the data.

5.5. Episode E

Six contemporary ages between ~3300 and 3700 years B.P. with overlapping 1σ ranges were obtained from three locations near Ten Mile Hill (TMH-1, TMH-3, and TMH-5), located near Charleston, and from BLUF-D (BLUF-14A and BLUF-15C). These dates were constrained by a minimum age near Georgetown (GEO-2B) and a maximum age near Gapway (GW-1C) in the north; a minimum age near Ten Mile Hill (TMH-2A), a maximum age near Hollywood (HOL-1A) near Charleston; and a maximum age at BLUF-D (BLUF-15B) in the south (Figures 5e and 6). The weighted average of these contemporary ages is 3548 ± 66 years B.P., which is the age we assign to episode E.

Because evidence for episode E was found at sites in the north, middle, and south, we interpret the size of this (these) earthquake(s) to be at least as big as the 1886 Charleston earthquake and its location to be near Charleston, and we assign it a magnitude M 7+. Using *Ambraseys'* [1988] formula and a distance of 100 km (distance to BLUF-D), we get M 7.0.

5.6. Episode F

Episode F has been inferred from one contemporary age for a sample at Gapway (GW-2C) and tight-bracketing constraint from Hollywood (HOL-3B) and from loose maximum constraints from Hollywood (HOL-3A) and Conway (CON-1) and loose minimum constraints from Georgetown (GEO-2B) and Ten Mile Hill (TMH-2A) (Figures 5f and 6). The two ages obtained from HOL-3A and HOL-3B do not provide a tight age constraint for episode F and could be evidence for a later earthquake (episode G). The age of episode F is 5038 ± 166 years B.P., based on one contemporary age with possibly a northern source. We ascribe it a magnitude M ~6.0.

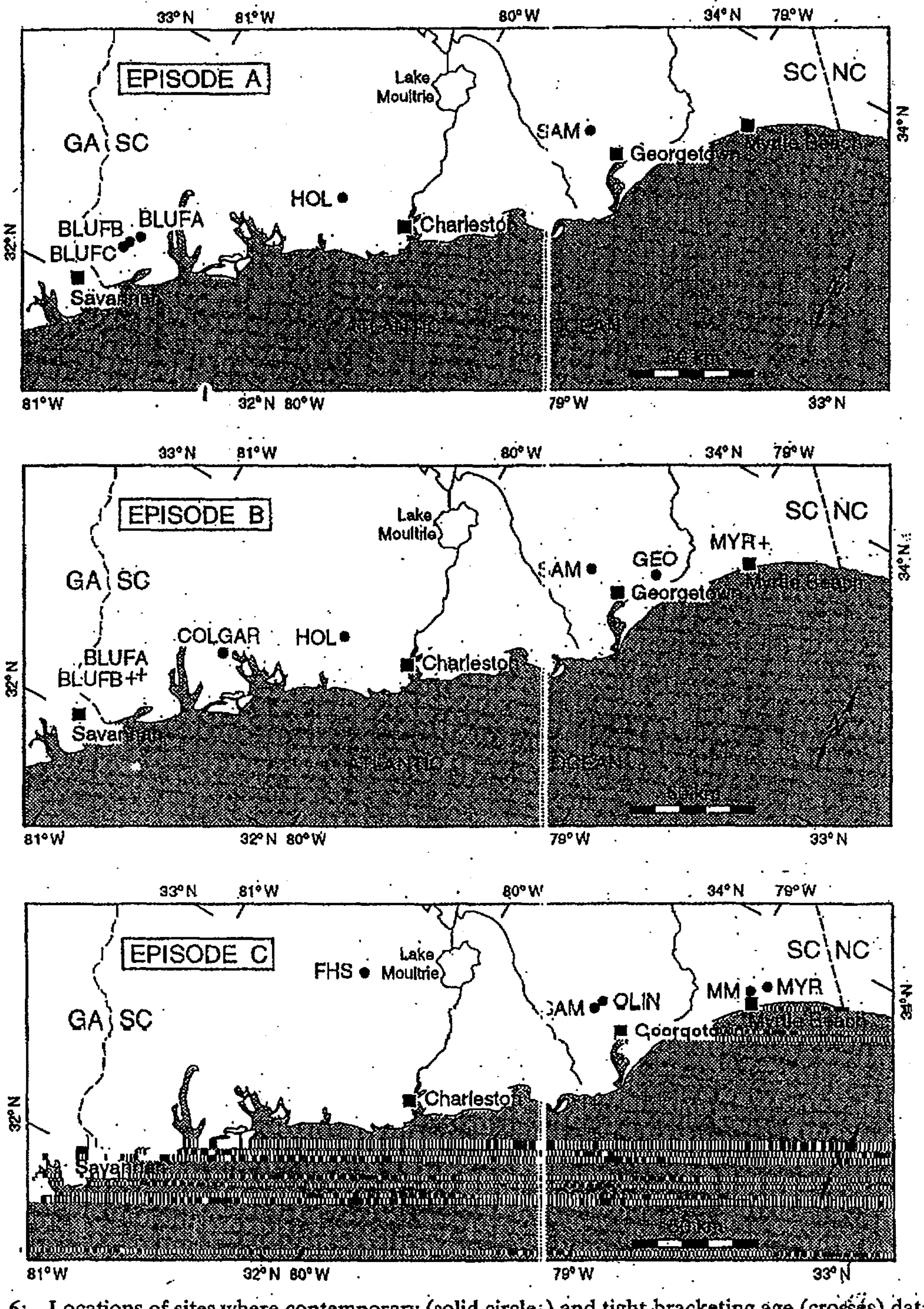

Figure 6: Locations of sites where contemporary (solid circles) and tight-bracketing age (crosses) data were obtained for episodes A–G.

5.7. Episode G

The age of this liquefaction episode is not defined by any contemporary ages. It is determined from tight-bracketing age constraints at Ten Mile Hill (TMH-4A and TMH-4B) near Charleston and at Malpherous (MAL-1A and MAL-1B) to the south (Figures 5g and 6). Tight maximum age is provided by a sample from Conway (CON-1), and tight minimum age constraint is provided by a sample from Myrtle Beach (MYR-2). Loose age constraints are provided by samples from Hollywood (HOL-3A and HOL-3B); their ages could also be evidence of episode F. Other samples from Malpherous (MAL-1E and MAL-1F) and Southport, North Carolina, provide loose constraints. The assigned age of episode G (5300–6300 years B.P.) is estimated from the tight constraint provided by MAL-1A and MAL-1B and slightly looser constraint provided by TMH-4A and TMH-4B. We assign it a magnitude *M* 7+ and place it near Charleston because evidence of this episode was found in northern, middle, and southern sites. Application of *Ambraseys*' [1988] formula and a distance of 140 km to MYR give *M* 7.2.

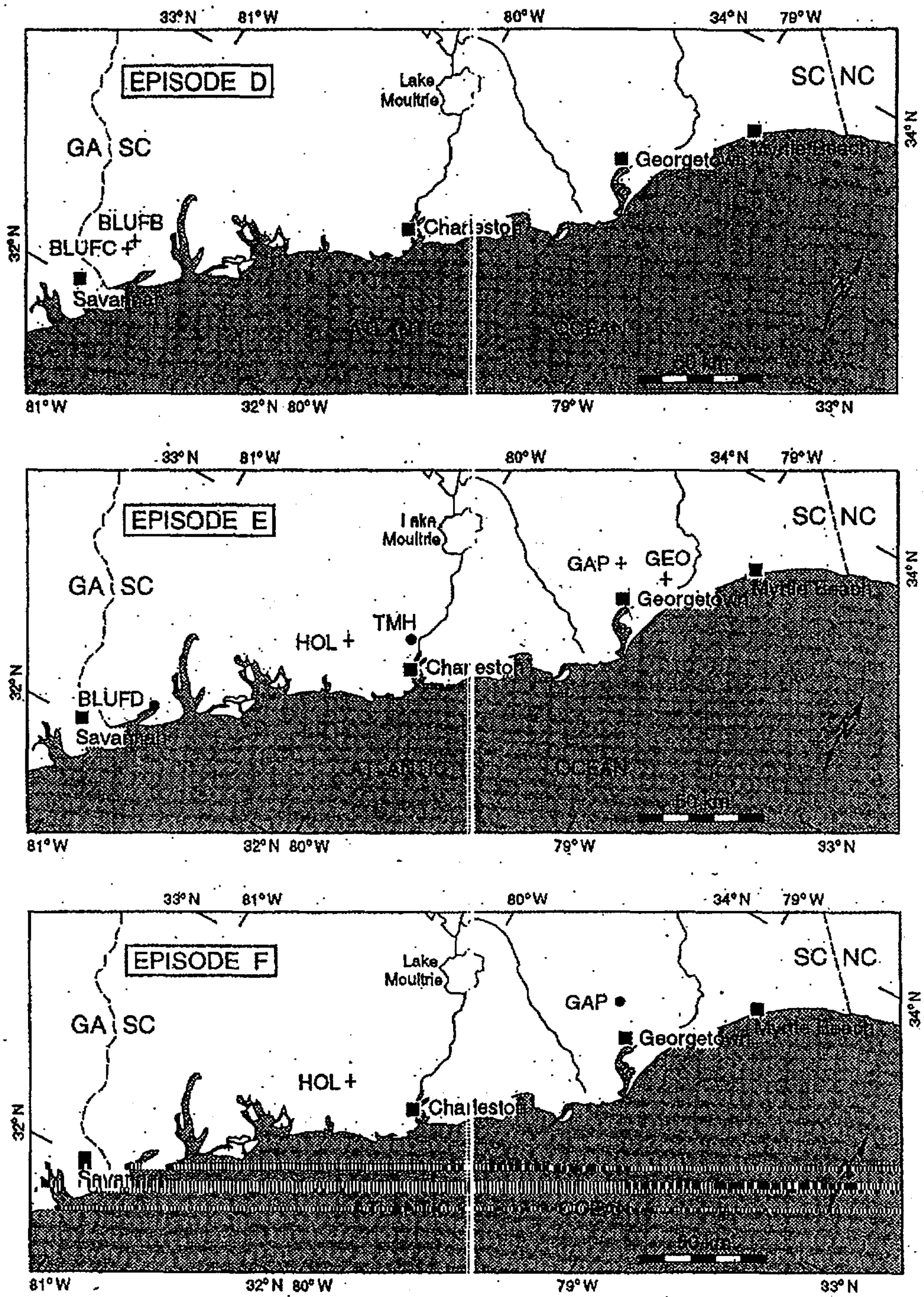

Figure 6. (continued)

6. Discussion

Calibrated ages of radiocarbon samples from sandblows at multiple sites in South Carolina suggest the occurrence of seven prehistoric earthquakes, large enough to cause liquefaction. The inferred ages of these episodes are 546 ± 17, 1021 ± 30, 1648 ± 74, 1754–2177, 3548 ± 66, 5038 ± 166, and 5300–6300 years B.P. Age ranges are used when the age is based primarily on bracketing ages.

The analysis presented in section 5 leads to two scenarios for the inferred prehistoric seismicity. In the first, there are three possible seismic source zones: One is located near Charleston, another is located near Georgetown (northern source), and the third is located near Bluffton (southern source). The second scenario involves all earthquakes occurring in the Charleston seismic zone. The timing of the earthquakes in the two scenarios is summarized in Table 3.

The possibility of a source zone outside of the Charleston area has been suggested earlier. For example, *Weems and Obermeier* [1990] suggested that the older ages (>5750 years B.P.) at Conway and (>8770 years B.P.) at Southport, North Carolina, might be evidence of a northern source. *Amick and Gelinas* [1991] attributed (our) episode C to a northern source.

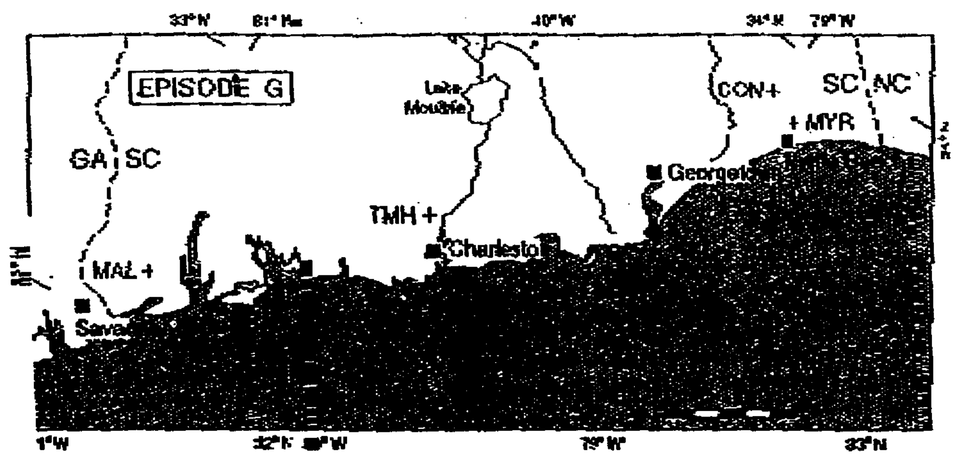

Figure 6. (continued)

Rajendran and Talwani [1993] attributed (our) episode D to a southern source.

Historical accounts clearly show that the 1886 earthquake occurred near Charleston. Evidence of episodes A (546 ± 17 years B.P.), B (102[illegible] ± 30 years B.P.), C′ (16[illegible]3 ± 70 years B.P.), E (3548 ± 66 years B.P.), and G (5300–6[illegible]00 years B.P.) is present in the northern, middle, and southern sites (Figure 6). These are also interpreted to be Charleston events, and we assign them magnitudes comparable to the Charleston 1886 [illegible]

Evidence of episode C comes primarily from northern sites and one inland site (FHS) with no corroborative ages from southern or Charleston sandblows. In scenario 1 we assign it a northern source, with $M \sim 6.0$. Episode D is based primarily on bracketing ages for sandblows at BLUF-B and BLUF-C. We assign it a southern source with $M \sim 6.0$. If episode C and D are associated with one episode C′, then its magnitude is also $M \sim 7+$. Episode F is based primarily on a contemporary age at Gapway (GW-[illegible]C), 4985 +218/−113 years B.P., which is statistically different from the inferred age of episode G, 5800 ± 500 years B.P. at the 1σ level and the same at the 2σ level. Two samples from Hollywood (HOL-3A and HOL-3B) provide loose age constraints, for both episodes F and G. If they are associated with episode G, then episode F is inferred only from data from Gapway and Conway, i.e., only the northern sites. In this scenario (scenario 1) we assign a magnitude $M \sim 6.0$ to the northern source. If HOL-3A and HOL-3B are associated with episode F, then we assign a larger magnitude to episode F, M 7+ (scenario 2). Clearly, more data are needed to resolve between the two scenarios presented above.

6.1. Ages of Prehistoric Earthquakes and Sea Levels

In the South Carolina Coastal Plain all evidence of prehistoric earthquakes is based on studies of seismically induced liquefaction features. An essential requirement for the development of the sandblows is the presence of a saturated [illegible] source sand horizon and a shallow ground water table (about <3–4 m deep for the various sandblows investigated in this study). A priori, we have no way of knowing the depth of the ground water table at the time of the prehistoric earthquakes. Except for the inland site at Four Hole Swamp the other sandblows are in beach ridges within ~20–30 km from the present coast line. So we make a simple assumption that the prehistoric ground water table levels were directly related to the corresponding age sea levels, data for which are available.

Prehistoric sea levels have been studied by several workers. *Fairbanks* [1989] provided a continuous and detailed record of the sea level offshore of Barbados over the past 17,000 years. Sea level was ~10 m lower than present sea level at ~6000 years B.P. and considerably lower before that. If the ground water table at liquefaction sites was correspondingly deeper than today, it would be difficult for liquefaction to occur and reach the surface, because the water table would be too deep. Therefore the "clock" started at ~6000 years B.P., possibly

Table 3. Two Scenarios for Paleoearthquake Ages and Source Zones

Liquefaction Episode	Age, years B.P.	Scenario 1		Scenario 2	
		Source	Magnitude*	Source	Magnitude*
1886 AD	113	Charleston	7.3	Charleston	7.3
A	546 ± 17	Charleston	7+	Charleston	7+
B	1021 ± 30	Charleston	7+	Charleston	7+
C	648 ± 74	northern part	~6.0	...	—
C′	683 ± 70	...	...	Charleston	7+
D	966 ± 212	southern part	~6.0	...	—
E	548 ± 66	Charleston	7+	Charleston	7+
F	038 ± 166	northern part	~6.0	Charleston	7+
G	800 ± 500	Charleston	7+	Charleston	7+

*Magnitude is M_w; 1886 magnitude is from *Johnston* [1996].

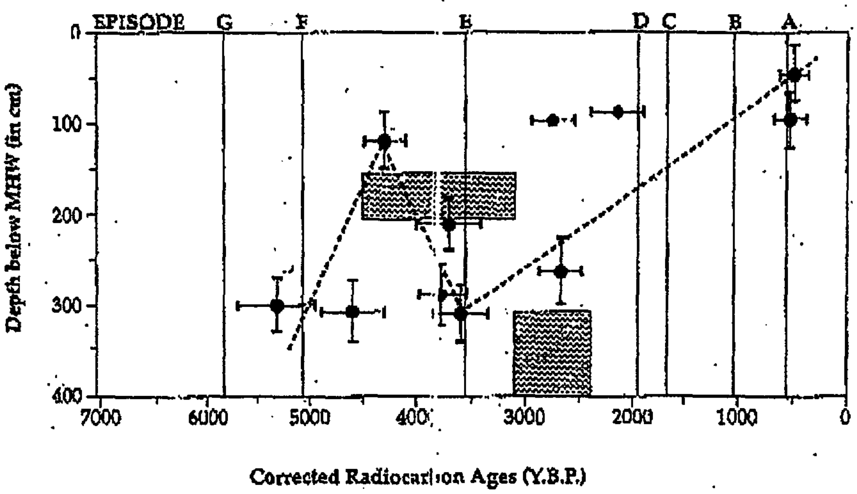

Figure 7. Depths below mean high water (MHW) level inferred to represent late Holocene sea levels for the SCCP, from *Scott et al.* [1995] (solid circles) and from *DePratter and Howard* [1981] (stippled pattern). Age data from *DePratter and Howard* [1981] were calibrated before plotting. The times of episodes A–G are shown by solid vertical lines for comparison.

explaining the age of the oldest liquefaction episode indicated by all of the studies conducted to date.

Evidence of late Holocene sea level fluctuations have been identified in the South Carolina and Georgia Coastal Plains [*DePratter and Howard*, 1981; *Colquhoun and Brooks*, 1986; *Gayes et al.*, 1993; *Scott et al.*, 1995]. These studies identified a highstand during the past 6000 years of relative sea level between ~4500 and 3100 years B.P. *DePratter and Howard* [1981] used historical data together with dated archaeological artifacts, submerged in-place tree stumps, and numerous buried trees in northeast Georgia near Wilmington Island and neighboring South Carolina (Figure 1). They found that the sea level reached −1.5 to −2 m mean sea level (msl) by ~4500 years B.P., began to lower ~3100 years B.P., was ~3 to −4 m for ~500–600 years, and then rose to its present levels around 2400 years B.P. *Gayes et al.* [1993] obtained a relative sea level curve from tidal wetland deposits of Murrell's Inlet, South Carolina, 30 km northeast of Georgetown (Figure 1). They also found a sea level highstand between ~5300 and 3600 years B.P. [*Gayes et al.*, 1993, Figure 6, p. 159] wherein water oscillated from −3 m about 5300 years B.P. to −1 m msl by 4280 years B.P. and then fell to −3 m by 3600 years B.P. before rising again to its present position. At the Santee River delta (25 km south of Georgetown) they present evidence for deepening of sea level to about −5–6 m msl during the period from 3200 to 2000 years B.P. They attribute the lower differential Holocene submergence to sediment loading by the Santee delta. *Scott et al.* [1995] added micropaleontologic constraints to the results of *Gayes et al.* [1993] and confirmed their conclusions. *Colquhoun and Brooks* [1986] developed a Holocene sea level curve for the southeastern United States through a study of marsh stratigraphy and archeological sites in marsh and interriverine areas from near Georgetown to Savannah, Georgia. They also found a sea level rise from about −4 m about 5000 years B.P. with a highstand (−1 m msl) ~4000 years B.P. Their data showed several fluctuations in sea level and were not well constrained.

The effect of ground water level on the formation of sandblows is examined by comparing prehistoric sea level curves with the times of episodes A–G (Figure 7). Both at Murrell's Inlet [*Scott et al.*, 1995] and near Savannah, Georgia [*DePratter and Howard*, 1981], there was a highstand higher than about −2 m msl of relative sea level from ~4500 to 3100 years B.P., a lowstand lower than about −3 to 4 m msl from 3000 to 2400 years B.P., and shallower water levels, higher than −2 m msl for the past 2000 years. We note that at the time of occurrence of episodes A, B, C, and D (and C′) the water levels were shallower than −2 m msl, thus making widespread liquefaction possible for Charleston-type events (episodes A and B) or smaller local earthquakes (episodes C and D). If the groundwater levels between 3000 and 2000 years B.P. in other parts of the SCCP were also low, as at Santee (−5 to 6 m msl), we would not expect liquefaction features to reach the surface, providing a possible explanation for the absence of sandblows of that age. The absence of sandblows older than episode G could be due to water levels being too low to cause liquefied sands to reach the surface and not due to an absence of earthquakes.

The inferred occurrence of only one earthquake (episode E) in the 3000 year period between episodes A–D and episodes F and G could be due to temporal clustering of seismicity, fluctuation water levels, or their evidence having been obliterated. Our data do not allow us to distinguish between these alternatives. Thus, for estimating recurrence rates of prehistoric earthquakes based on paleoliquefaction events we consider the paleoliquefaction record to be complete for the past 2000 years. Because the paleoliquefaction record may not be complete for the period between ~5800 and 2000 years B.P., the recurrence intervals between older paleoliquefaction events may not be representative of the paleoliquefaction rates in the SCCP. Thus, in estimating the recurrence rates of earthquakes in the SCCP we place greater emphasis on the data for the past 2000 years B.P., i.e., up to episode D.

6.2. Recurrence Rates

In estimating the recurrence rate for scenario 1 we assume that the liquefaction observed near Georgetown and dated at ~1650 years B.P. (episode C) resulted from an earthquake on a northern source. We further assume that episode D, which occurred ~2000 years B.P., was associated with a southern source near Bluffton. In this scenario no earthquakes occurred in the Charleston source at 1650 or 2000 years B.P. Thus, in the past 2000 years we have three earthquakes located near Charleston; 1886 A.D., 546 years B.P., and 1021 years B.P. with an average recurrence rate of 454 ± 21 years. The next known (older) earthquake associated with liquefaction occurred ~3550 years B.P. (Table 3). Evidence for any (?) earthquake(s) between ~2000 and 3550 years B.P. could be missing. If we assume that we have one missing earthquake midway between 2000 and 3550 years B.P. (for which there is no record of a liquefaction feature), the mean recurrence rate for the Charleston source is ~859 ± 532 years. If we assume two equally spaced missing earthquakes between 2000 and 3550 years B.P., the mean recurrence rate for the Charleston source zone is 687 ± 405 years. For the northern and southern sources, on the basis of one event each in the past 2000 years, we assign a recurrence rate of 2000 years for M 6.0 earthquakes.

For scenario 2 (Table 3) we assume that there was only one earthquake associated with liquefaction between ~1000 and 2000 years B.P. and that it occurred at the Charleston source at 1683 years B.P. (episode C'). In this scenario there are four Charleston earthquakes before 2000 years B.P. (1886 A.D., 546 years B.P., 1021 years B.P., and 1683 years B.P.), with a mean recurrence interval of 523 ± 100 years B.P. In anticipation of additional data we suggest a recurrence rate between 500 and 600 years for M 7+ earthquakes at Charleston and ~2000 years for M 6.0 events at the northern and southern sources in the SCCP.

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EXHIBIT 6

Status Report on the EPRI Fuel Cycle Accident Risk Assessment

EPRI

EPRI NP-1128
Project 767-1
Interim Report
July 1979

Table 5.3.2

DOMINANT RISK CONTRIBUTING ACCIDENTS IN THE MOX PLANT

Accident Number	Accident Description
1	Earthquake in excess of the design basis
2	Aircraft crash into headend area
3	Hydrogen explosion in ROR reactor
4	Hydrogen explosion in sintering furnace
5	Ion exchange resin fire
6	Dissolver explosion in wet scrap recovery
7	Loaded final filter failure
8	Criticality accident
9	Plutonium shipping container damage
10	Tornado in excess of design basis

Table 5.3.3

ISOTOPIC CONTENT OF PLUTONIUM AGED 1 YEAR AFTER REPROCESSING
(from GESMO, Ref. 6)

Isotope	1st Recycle (weight %)	2nd Recycle (weight %)	3rd Recycle (weight %)	4th Recycle (weight %)
^{238}Pu	2.5	3.2	4.2	5.
^{239}Pu	57.	40.	34.	31.
^{240}Pu	23.	30.	30.	27.
^{241}Pu	11.	15.	16.	20.
^{242}Pu	5.2	10.	15.	20.
^{241}Am*	0.63	0.81	0.86	0.86

*Because of decay of ^{241}Pu during the first year after reprocessing. The curies per gram are: ^{238}Pu - 16.9, ^{239}Pu - 0.06, ^{240}Pu - 0.22, ^{241}Pu - 114, ^{242}Pu - 0.0039 and ^{241}Am - 3.26. This gives a weighted mean for first recycle of 13 Ci/gm.

EXHIBIT 7

NUREG/CR-6427
SAND99-2553

Assessment of the DCH Issue for Plants with Ice Condenser Containments

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Consequently, core damage arrest might only be important in determining non-DCH loads at low RCS pressures. Because best estimate steam spike loads are not containment threatening, core damage arrest has no impact on the results of this study. Core damage arrest played a much more important role in the NUREG-1150 study because it *also* precluded lower head failure for other CDIs and in some additional scenarios that otherwise would have lead to containment threatening DCH and liner attack events.

Table 7.4 shows that all plants, except McGuire, have early containment failure probabilities (full power internal events given core damage) in the range of 0.35% to 5.8%. These integral results of early containment failure are qualitatively consistent with published IPE results for these plants. The early containment failure probability was 13.9% for McGuire. The higher containment failure probability is dominated by the high SBO frequency and the relatively weak containment for McGuire. We have not investigated why our assessment for McGuire is seven times larger than the IPE value of 2%.

For perspective, we note that the DCH overpressure failure probability was less than or equal to 10^{-3} for the vast majority of PWRs with large dry or subatmospheric containments (Pilch et al. 1996 and Pilch et al. 1997). Because DCH is thought to be the dominant mode of early containment failure in most of these PWRs, we conclude that ice condenser plants are at least two orders of magnitude more vulnerable to early containment failure than other types of PWRs. This relative ranking of ice condenser plants with the remaining PWRs is generally consistent with perceived notions; but surprisingly, it is not consistent with results summarized from the IPEs themselves. Summarizing IPE results, NUREG-1560 (NRC 1996) showed that a large number of PWRs with large dry or subatmospheric containments report mean early containment failure probabilities in excess of 10%, while none of the ice condenser plants reported early failures greater than 2.4%. NUREG-1560 further cites DCH processes as the main contributor to early containment failure in PWRs with large dry or subatmospheric containments. In light of more recent NRC estimates (Pilch et al. 1996 and Pilch et al. 1997), we conclude without judging the relative quality of the IPEs, that many utilities with large dry or subatmospheric containments must have been overly conservative in their treatment of HPME probabilities and DCH loads.

The early containment failure estimates of this study are restricted to full power internal events. Bypass events, low power shutdown events, and external events must be considered to have a complete risk informed perspective of early containment failure risk. We note, however, that bypass events have nothing to do with DCH. Furthermore, HPME/DCH processes are not likely to occur in low power shutdown events because the RCS pressure is expected to be low; however, there are some scenarios where loss of RHR could lead to repressurization if the pressure boundary is sealed.

The core damage phenomenology for external events is similar to that for internal events. Risk-informed regulation could be better served if insights from this study were factored into fully integrated assessments of risk for ice condenser plants.

Table 7.5 shows the relative contributions of external events and internal events to total core damage frequency. For Catawba and McGuire, the CDF associated with external events can be a analysis at either single or multiple accident temperatures. For those that determined the capacity at different temperatures, the analysis closest to 400 K (260°F) was selected as best representing the accident temperatures expected in the reactor containment building during vessel breach.

We observed that the licensee's level of effort and our estimate of the reliability of these containment fragility curves varied significantly. In some cases, a detailed analysis was performed for every possible failure mode. An overall cumulative failure curve was determined by combining each mode of failure, while some IPEs simply used containment fragility curves derived from other containments or simply shifted other plant's fragility curves based on their determination of the difference in ultimate capacity.

Appendix D in Pilch et al. (1996) briefly discusses (when given enough information) how the fragility curves were determined from each IPE. In addition, the process of digitizing, fitting and tabulating the curves or data given in the IPEs is discussed for every plant, and the detailed results are also tabulated

Functional representations of fragility are subject to possible error when extrapolated to low failure frequencies, because excessive extrapolation to low failure frequencies could lose or violate the physical basis most of the curve rests on. In other cases, some IPEs conservatively tie the low end of the fragility curve to the design pressure. Consequently, the IPE fragility curves might be quite conservative in the tails. On the other hand, the digitizing process is subject to human error and is dependent on the quality of the working curve. In a few cases, we supplied a curve fit to median values (5% and 95%), and extrapolation to lower failure frequencies may involve error. It will be shown that the assessment of early containment failure probability can be sensitive to uncertainties in the fragility curves.

Table 6.1 provides a concise summary of key plant-specific fragility data for each Westinghouse plant with an ice condenser containment. We note that all ice condenser containments are free-standing steel shells, except DC Cook, which is a reinforced concrete containment. We see that large variations in containment strengths exist. DC Cook is the least robust containment with a failure pressure of 45 psig, at a failure frequency of 10%. Watts Bar and Catawba are the strongest containments with failure pressures of 71 psig, at the same failure probability. Thus, we conclude that a containment's fragility is plant-specific. This is illustrated further in Figure 6.1 which compares the fragility curves for all the plants. We note in Table 6.1 that IPE assessments of fragility for Sequoyah suggest that the containment is more robust (particularly in the low-end tail) compared to NUREG-1150 assessments of the containment fragility for Sequoyah.

We note that the ice condenser plants are substantially less robust than other Westinghouse plants with large dry or subatmospheric containments. Table 6.1 shows that the mean of the containment failure pressure for all ice condenser plants is 62.8 psig at a failure frequency of 10%. The comparable value for all Westinghouse plants with large dry or subatmospheric containments is 113.1 psig. Ice condenser containments can afford to be less robust because of their reliance on ice beds as a pressure suppression feature for design basis accidents.

for DBA conditions. CONTAIN has also been benchmarked against key experiments that emphasize each of the three sources of containment loads noted above. However, there are no integral DCH tests in ice condenser geometry to fully validate CONTAIN for this application.

Steam sources were taken from a SCDAP/RELAP5 SBO calculation and used as input to a CONTAIN code model of the ice condenser containment. CONTAIN predicted that approximately half the ice remained at the time of vessel breach. A fully consistent calculation of ice inventory for non-SBO events was not performed as part of this study, but a review of NUREG-1150 quantifications shows that 10-50% of the ice remains at the time of predicted vessel breach for DCH relevant scenarios. NUREG-1150 quantifications showed total or almost total ice melt for a number of scenarios; these tended to be cases involving large LOCAs or induced large LOCAs that preclude DCH.

CONTAIN calculations performed in support of the present effort show that there is a potential for the ice to be considerably more effective in preventing threatening DCH loads than indicated by the earlier studies, provided igniters (and ARFs) are operating prior to vessel breach. The principal reason is that the combination of limited metal in the melt and oxygen starvation in the lower containment resulted in a much smaller contribution from the combustion of DCH-produced hydrogen, and the ice was calculated to be very effective in suppressing pressurization owing to superheated gas and steam.

CONTAIN calculations showed that no ice condenser plant is inherently robust to all credible DCH or hydrogen combustion events in a station blackout (SBO) accident. The containment is threatened by hydrogen combustion events alone because igniters, which are AC-powered, are not available to mitigate the accumulation of very high concentrations of hydrogen in the containment. Hydrogen combustion, initiated by and in conjunction with a DCH event is even more threatening. The ice beds were found to significantly reduce DCH loads in a SBO accident, but not to a level that did not threaten the containment. CONTAIN predicted non-threatening containment loads for non-SBOs provided ice or one train of containment sprays is available. If the refueling water storage tank has emptied and approximately 50% of more of the ice is melted, the reactor cavity will be deeply flooded and the nature of containment loads change from DCH to non-threatening steam spikes.

The containment event tree is intended to give each containment challenge its proper probabilistic weighting based on plant specific core damage frequencies, phenomenological probabilities, and plant specific fragility curves. The CET event tree was benchmarked against NUREG-1150 to ensure that all significant top events were reasonably represented in a simplified CET patterned after NUREG-1150. Detailed comparisons proved this to be the case. The CET was further simplified by introducing some conservative assumptions and specific quantifications were updated based on more recent NRC-sponsored research.

A plant-specific evaluation of the CET showed that all plants, except McGuire, had an early failure probability (given core damage) within the range 0.35% to 5.8% for full power internal events. These integral estimates of early containment failure are qualitatively consistent with published IPE results for these plants. The early containment failure probability, as computed here, was 13.9% for McGuire. This higher containment failure probability for McGuire is dominated by the relatively high SBO frequency and the relatively weak containment for McGuire. The IPE assessments of early containment failure at McGuire (2%) are significantly lower than our assessments; however, we have not investigated the reasons for this difference.

Phenomenological uncertainties are large, but a fully integrated uncertainty study was outside the scope of this effort. However, selected sensitivity studies were performed here to illuminate the importance of certain quantifications and to examine the importance of certain accident management procedures that might be proposed. Reduction in the hot leg failure probability and the probability of a stuck open power-operated relief valve (PORV) after uncovery of the top of actual fuel (UTAF) had no significant impact of the results of this study. Reduction in the hot leg failure probability increases the probability of early containment failure for those plants with a large SBO frequency, but not to the point that conclusions regarding compliance with NRC goals would change. An additional sensitivity study assuming intentional depressurization by the operators after UTAF also had no impact on the conclusions of this study. All plants, especially McGuire, would benefit from a reduction in SBO frequency or some means of hydrogen control that is effective in SBOs. The resulting risk reduction is greater than an order of magnitude for all plants.

Assuming igniters and air return fans are not operational (e.g. SBOs), uncertainties in containment loads are dominated by uncertainties in hydrogen combustion phenomena and the amount of clad oxidized during core degradation. For non-SBOs, uncertainties in containment loads are dominated by uncertainties in modeling, the availability of sprays, the ice inventory at vessel breach, and the melt mass. We use the mean fragility curves as reported in the IPEs, which have not been reviewed. These fragility curves are steep with a short low-end tail, and any uncertainties in these fragility curves could have a significant impact on computed containment failure probabilities.

Consistent with perceptions of the technical community, this study shows that ice condenser plants are substantially more sensitive to early containment failure than PWRs with large dry or subatmospheric containments. These perceptions, however, are not consistent with IPE results summarized in NUREG-1560 that show many PWRs with large dry or subatmospheric containments report early containment failure probabilities in excess of 10% given a core damage accident, while none of the ice condenser plants reported early failures greater than 2.4%. NUREG-1560 cites DCH processes as the main contribution to early containment failure in PWRs with large dry or subatmospheric containments. In light of more recent NRC estimates of DCH-induced containment failure probabilities, we conclude that many utilities with large dry or subatmospheric containments were overly conservative in their treatment of HPME probabilities and DCH loads.

To develop a more integrated perspective for risk-informed regulation, it is recommended that the insights of this study be factored into more complete Level II analyses for each significant plant damage state and that the evaluation of early containment failure be evaluated not only for internal events, but also for external events, low power shutdown events, and bypass events. For completeness, we recommend that a formal uncertainty study be performed to quantify the impact of identified uncertainties on early containment failure; however, uncertainties in the fundamental DCH processes of dispersal, fragmentation, and debris/gas heat

EXHIBIT 8

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Public Health Risks of Substituting Mixed-Oxide For Uranium Fuel in Pressurized-Water Reactors

Edwin S. Lyman[a]

The U.S. Department of Energy (DOE) has awarded a contract to the consortium Duke Cogema Stone and Webster (DCS) to dispose of up to 33 tonnes of excess weapons-grade plutonium (WG-Pu) by irradiating it in the form of mixed-oxide (MOX) fuel in four U.S. commercial pressurized-water reactors (PWRs). This paper estimates the increase in risk to the public from using WG-MOX at these reactors and finds that it exceeds recently established Nuclear Regulatory Commission (NRC) guidelines. Therefore, the NRC will have a technical basis for prohibiting the use of MOX at these reactors unless the risk that they will experience a severe accident can be significantly reduced.

MOX fuel will displace a fraction of the low-enriched uranium (LEU) fuel that these reactors currently use. Because MOX cores have greater quantities of plutonium and other actinides than LEU cores throughout the operating cycle, the source term for radiological releases caused by severe reactor accidents will be greater for MOX-fueled PWRs. In this paper, the radiological consequences to the public from containment failure or bypass accidents at MOX-fueled PWRs are calculated, and compared to those resulting from the same accidents at LEU-fueled PWRs.

This paper finds that compared to LEU cores, the number of latent cancer fatalities (LCFs) resulting from an accident with core melt and early containment failure would be higher by 39%, 81% or 131% for full WG-MOX cores, depending on the fraction of actinides released (0.3%, 1.5% or 6%). Under the DCS plan, in which WG-Pu will be purified using an aqueous process and only 40% of the core will be loaded with WG-MOX, the number of LCFs would be 11%, 25% or 30% higher, respectively. The average LCF risk to individuals within ten miles of a severe accident approximately doubles for a full WG-MOX core, and increases by 26% for a DCS core.

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These results are of particular concern for the nuclear plants in the DCS consortium, Catawba and McGuire. These plants have ice-condenser containments, which Sandia National Laboratories estimates are at least two orders of magnitude more vulnerable to early failure than other types of PWR containments.

The findings of this paper also apply to the proposed use of WG-MOX in VVER-1000 reactors in Russia, which meet less stringent safety standards than U.S. reactors.

INTRODUCTION

Plutonium Disposition

In January 1997, the U.S. Department of Energy (DOE) decided to pursue a "dual track" policy for disposing of approximately 50 tonnes of plutonium produced for weapons programs that have been declared excess to military needs. The two tracks refer to different approaches for converting separated plutonium into a dilute and highly radioactive form that is more difficult to return to weapons.

Under one approach, known as "can-in-canister" immobilization (CIC), plutonium will be incorporated into chemically stable ceramic discs. These discs will in turn be embedded in canisters of "vitrified" (glassified) high-level radioactive waste (VHLW) at the Defense Waste Processing Facility (DWPF) at the Savannah River Site (SRS) in South Carolina. DOE is planning to use CIC for approximately 17 tonnes of excess plutonium in impure forms. The CIC facility will be sited at SRS adjacent to the DWPF.

Under the other approach, plutonium will be used to produce "mixed plutonium-uranium oxide" (MOX) fuel assemblies, which will be irradiated in a number of U.S. commercial light-water nuclear reactors (LWRs), displacing some or all of the low-enriched uranium oxide (LEU) fuel the reactors currently use. DOE is planning to utilize this option for 25.6 tonnes of weapons-grade plutonium (WG-Pu).

Both processes are regarded by most experts as roughly comparable in their ability to render the plutonium as inaccessible as the plutonium in commercial spent nuclear fuel, thereby meeting the "spent fuel standard" defined by the National Academy of Sciences (NAS).[1] However, DOE decided to pursue both tracks for a number of reasons, one being the desirability of having a backup strategy in case one approach did not succeed.

In 1998, DOE issued a Request for Proposals, seeking vendors interested in providing MOX fuel fabrication and irradiation services. Of the three proposals submitted, two were quickly eliminated for failing to meet basic requirements. In March 1999, DOE signed a contract with the third party, a consortium called Duke Cogema Stone & Webster (DCS), which included the

EXHIBIT 9

WASTE PRODUCTION IN FRENCH MOX FABRICATION FACILITIES

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Version 2, Paris, 10 August 01

Introduction

The following is a brief note on the waste generation and management at the French MOX fuel fabrication facilities and the MELOX plant in Marcoule in particular. Detailed information is not publicly available and COGEMA has turned down any request for information on waste production of the MELOX plant arguing commercial confidentiality.[1]

WISE-Paris has estimated the waste ratio on the basis of the available information. Any more precise calculation is currently not possible without COGEMA's willingness to a minimum of transparency on the issue.

Waste Generation at French MOX Fabrication Facilities

Among the MELOX facilities on the Marcoule site, there is a unit (called *Unité de Chamottage*) where discarded pellets can be grinded in view of the re-introduction into the process. According to unpublished information, the unit has a capacity of 8% of the initial annual licensed throughput of 101.3 t HM. It started operating at the same time as the rest of the MELOX facility.[2]

Table 1: Unirradiated Scrap MOX stored at La Hague Cooling Ponds (in tHM)[3]
(as of 1st January 2001)

Origin	Quantity
MELOX (F)	45
Cadarache (F) + Dessel (B)	35
Hanau (D)	10
Total	90

Source: DRIRE[4] and COGEMA

Calculation of MELOX Waste Production Factor

Considering that :

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[1] see COGEMA, letter to WISE-Paris, dated 8 August 01 (attached as PDF)

[2] Personal communication, DRIRE-Languedoc Roussillon, 10 August 2001 (Direction Régionale de l'Industrie de la Recherche et de l'Environnement, Regional representative of the State nuclear safety authority).

[3] The figures are rounded to the ton.

[4] personal communication, DRIRE-Basse Normandie, 31 July 2001 (Direction Régionale de l'Industrie de la Recherche et de l'Environnement, Regional representative of the State nuclear safety authority)

- MELOX has been operating since 1996;
- MELOX has fabricated 434.6 tHM of MOX as of 31.12.2000;

Table 2: MELOX production output by year (in tHM)

Year	Quantity
1996	30.4
1997	101.2
1998	101.0
1999	101.0
2000	101.0
Total	**434.6**

- La Hague ponds contained 45 tHM of MELOX scrap MOX as of 31 December 2000;

it can be calculated that :

- If 8 % of the total scrap MOX is treated in the *Unité de Chamottage* and 45 tHM (or 10.4 %) were sent to La Hague;

• The average MELOX MOX waste factor on the operating period 1996-2000 would have been 18.4 %.[5]

Destination of Scrap MOX

COGEMA considers that all of the scrap MOX can be "recycled", that is reprocessed and the plutonium reused in .fresh MOX. However, currently COGEMA does not have any authorization to process any of the 90 tons of scrap MOX that is stored at La Hague in any of its installations at La Hague nor elsewhere.

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[5] Inofficial sources suggest that the scrap rate was as high as 50% in the first production year. However, it is unclear at what stage the products did not meet the technical specifications.

CERTIFICATE OF SERVICE
by Georgians Against Nuclear Energy
(Docket # 70-3098)

I hereby certify that copies of GANE's Contentions Opposing a License for DCS to Construct a Plutonium Fuel Factory at SRS was served on 8/13/01 to the list below via e-mail and hard copies served on August 14, 2001 with attachments via Fed EX to NRC and to DCS and by 1st Class U.S. Postal Service to others.

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