RAS 3795

November 29, 2001

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD
Ann Marshall Young, Chair
Charles N. Kelber, Administrative Judge
Lester S. Rubenstein, Administrative Judge

DOCKETED
USNRC

January 18, 2002 (4:08PM)
OFFICE OF SECRETARY

RULEMAKINGS AND
ADJUDICATIONS STAFF

In the Matter of

DUKE ENERGY CORPORATION

McGuire Nuclear Station, Units 1 and 2;	Docket Nos. 50-369 & 50-370
Catawba Nuclear Station, Units 1 and 2	Docket Nos. 50-413 & 50-414

Blue Ridge Environmental Defense League submittal of contentions in the matter of the renewal of licenses for Duke Energy Corporation (DUKE) McGuire Nuclear Stations 1 and 2 [McGUIRE] and Catawba Nuclear Stations 1 and 2 [CATAWBA].

And

Support for Motion to Suspend Proceeding Filed by NIRS 11/29/01

1. In accordance with 10 CFR 2.1203 (a) and 10 CFR 2.1203 (e), BREDL, hereby submits its formal written contentions to be considered for a hearing by the ASLBP regarding the renewal of licenses for Duke Energy Corporation (DUKE) McGuire Nuclear Stations 1 and 2 [McGUIRE] and Catawba Nuclear Stations 1 and 2 [CATAWBA].

2. BREDL hereby refers to the Atomic Safety and Licensing Board's October 16, 2001 for details (ASLBP No. 02-794-01-LR, with amended order regarding timing of submittals dated November 15, 2001) regarding history of the proceeding, form of contentions, location of filing date and other matters.

Template = SECY-037

SECY-02

3. In accordance with 10C.F.R. § 2.714(b)(2), the following contentions are hereby filed in this original submittal:

Contention Number	Title
One	Radiological impacts of routine operations and accidents
Two	**Human Reliability, Workforce Aging and Critical Skills Retention**
Three	Steam Generator Aging Management Program
Four	Aging Management of Ice Condensers
Five	
Six	
Seven	
Eight	
Nine	
Ten	

4. **Support for Motion to Suspend Proceeding Filed by NIRS 11/29/01.**

BREDL hereby supports the motion by NIRS to suspend proceedings until the Final Safety Analysis Reports (FSARs) are available. During the preparation of these contentions frequently encountered licensee references to the FSARs as validation of various aging management programs. There was no way for BREDL to review these claims.

A. Contention Number and Title

Contention One: Radiological impacts of routine operations and accidents

B. Contention

Offsite radiological impacts must analyzed as a Category 2 issue in Environmental Report.

C. Specific statement of the issue of law or fact to be raised or controverted

10CFR51, Subt. A, Appendix B identifies radiological exposures to the public during refurbishment, radiation exposure to the public from routine operations during the renewal term, collective offsite radiological impacts, and radiological doses during decommissioning as generic Category I NEPA issues for license renewal of nuclear power plants. The licensee applied the GEIS findings in its Environmental Report.

BREDL's contention is that analyses focused exclusively on the risks of cancer from ionizing radiation, and neglected to address information regarding birth defects (congenital anomalies), infant mortality, infant cancer incidence, and neurological effects.

D. Brief explanation of the basis or bases of the contention

This contention is based on the emergence of new information since the Commission rulemaking and the GEIS regarding health impacts from ionizing radiation:

1. A health study by Dr. Joseph Mangano focusing on the effects from operational closure of the Rancho Seco nuclear power plant near Sacramento California found "significant decreases in mortality (all causes and from congenital anomalies) and cancer incidence...for

fetuses, infants, and small children" following operational closure.[1]

A subsequent study by co-authored by Dr. Mangano has been accepted for publication by the *Archives of Environmental Health* will be published in the spring,[2] and then would be available for public dissemination and review in this proceeding. This study examined health impacts at eight nuclear power plants "at least 70 miles from other reactors" where operations have ceased. The study found that:

> Strontium-90 levels in local milk declined sharply after closing, as did deaths among infants living downwind and within 40 miles of each plant. These reductions occurred in the first two years after closing, were sustained for at least six years, and were especially pronounced for birth defects. Trends in infant deaths in proximate areas not downwind, and 40-80 miles downwind, from closed plants are not different than national patterns. In proximate downwind areas with available data, cancer incidence in children under age five fell significantly after shutdown. Changes in health after nuclear reactor closings may help in better understanding the relationship between low-dose radiation exposure and disease.[3]

2. In a recently published health study by KGA Associates in the Chernobyl Nuclear Power Plant area near Kiev, Ukraine and sponsored by the U.S. Department of Defense, the authors concluded:

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[1] Mangano, Joseph J. 2000. *Improvements in local infant health after nuclear power reactor closing.* Environmental Epidemiology and Toxicology (2000) 2, 32-36. Exhibit 1.

[2] Personal Communication with Dr. Joseph Mangano, November 28, 2001.

[3] Mangano, Joseph J., Jay M. Gould, Ernest J. Sternglass, Janette D. Sherman, Jerry Brown, and William McDonnell. *Infant Death and Childhood Cancer Reductions After Nuclear Plant Closing in the U.S.* (accepted for publication in the Spring 2001 issue of the *Archives of Environmental Health.*

"Taken collectively, the results of the data analysis are rather frightening. Initial dosages were from 1 rad to 183 rads. Our research suggests neurocognitive and physical decrements in performance 12 years AFTER a nuclear accident."[4]

In addition, the introduction to the study contains information about hot particles not previously released outside of Ukraine regarding "radioactive particles from the brown forest." The occurrence of hot particles following a major radionuclide release must be addressed in the Severe Accident Management Alternatives Analysis. (SAMAs).

3. This new information indicates that the licensee's analyses of radiological health impacts are deficient and should be addressed as a Category 2 issue:

a. The licensee identified radiation impacts from decommissioning alternatives as a Category I NEPA issue covered within the GEIS, and concluded in its analysis of Decommissioning Impacts in the Catawba ER that the "impacts of decommissioning would not be significantly different if decommissioning occurs after 40 years or after 60 years of operation. Duke has reviewed the environmental impacts of decommissioning of Catawba. These impacts are expected to be comparable to those environmental impacts described in the GEIS for impacts to: land use, water, air quality, ecological resources, human health, social and economic structure, waste management, aesthetics, and cultural resources."[5]

However, this did not take into account the availability of published data on the positive impacts of operational closure at Rancho Seco or the neurotoxic impacts of acute and chronic

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[4] Gamache, Gerald L, Dennis L. Reeves, Daniel M. Levinson, and Peter I. Bidiouk. 2001. *Neurocognitive and Physical Abilities Assessments Twelve Years After the Cherynobyl Nuclear Accident*. Prepared for the Defense Threat Reduction Agency (DTRA) U.S. Department of Defense. DTRA-TR-00-14. 120 Pages.

[5] Application to Renew the Operating Licenses of McGuire Nuclear Station, Units 1 & 2 and Catawba Nuclear Station, Units 1 & 2 June 2001. Applicant's Environmental Report Operating License Renewal Stage, Catawba Nuclear Station. Section 7.4, Decommissioning Impacts.

radiation exposure.

b. The licensee also identified Radiation exposures to public (license renewal term) and offsite radiological impacts (collective effects) as applicable to both Catawba and McGuire but encompassed in the GEIS as Category I NEPA issues. However, this did not take into account the availability of published data on the positive impacts of operational closure at Rancho Seco.

E. Statement of all appropriate facts and expert opinion to support contention

1. Health effects of ionizing radiation on infants and fetuses.

a. The published article by Dr. Joseph Mangano is submitted as Exhibit 1.

b. The following information submitted by the Radiation and Public Health Project for the Peach Bottom NPP relicensing proceeding is excerpted as follows:[6]

COMMENT ON ENVIRONMENTAL ISSUES

I. <u>INTRODUCTION</u>

The Radiation and Public Health Project (RPHP) is an independent, non-profit research and educational organization. The focus of RPHP's work is to assess the health effects of exposures to radioactive chemicals released into the environment by nuclear weapons tests and nuclear reactor operations. Founded in 1985, RPHP maintains a staff of professionals from the fields of radiation physics, toxicology, epidemiology, and statistics. Its members have published numerous medical journal articles and books on the radiation health issue (see Appendix).

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[6] *Comment on environmental issues regarding Exelon Corporation proposal to the U.S. Nuclear Regulatory Commission to re-license the Peach Bottom 2 and 3 reactors. November 21, 2001.* By the Radiation and Public Health Project, New York, NY. <u>Research Associates:</u>
Jay M. Gould, PhD, Director, Ernest J. Sternglass, PhD, Chief Scientist, Jerry Brown, PhD
Joseph Mangano, MPH, MBA, William McDonnell, MA, Marcia Marks, ACSW, LCSW
Janette Sherman, MD, William Reid, MD.

RPHP has documented substantial evidence linking environmental radioactivity with increased cancer risk. Perhaps the strongest evidence is the correlation of levels of radioactive Strontium-90 in baby teeth with risk of childhood cancer in Long Island. The following comment outlines RPHP findings and considers implications for the environmental impact of extending the operating license of the Peach Bottom 2 and 3 reactors.

II. <u>NUCLEAR REACTOR EMISSIONS AND HEALTH RISK</u>

More Reactors Produce More Power. Currently, 103 nuclear power reactors (at 64 sites) are operating in the U.S., producing about 20% of the nation's electricity. (1) About two-thirds of Americans live within 100 miles of at least one nuclear reactor. Operating utilities have permanently closed a total of 22 reactors. In addition, 128 reactors that were proposed by utilities to federal regulators were later canceled before commencing operations. (2)

Startup of new reactors and increased use of existing ones have caused the generation of electricity from reactors to nearly triple (248 million to 727 million gigawatt hours) from 1980 to 1999. (1) Present trends suggest that use of nuclear power reactors may proliferate in the future. The U.S. Nuclear Regulatory Commission (NRC) has received applications to extend the licenses of 43 reactors from the current life span of 40 years to 60 years. In addition, the Nuclear Energy Institute announced a goal of starting 50 new nuclear reactors at its annual meeting in May 2001.

Government Assessment of Health Risks is Deficient. Because radioactivity can damage human health, an accurate assessment of risk to the public is warranted. **However, current regulatory policies do not include any such risk assessment**. The NRC has approved the first five applications for reactor license extension, with no consideration of disease rates, including cancer, in persons living closest to reactors.

III. <u>NEED FOR MORE INFORMATION ON HEALTH</u>

Reactor Operations Release Cancer-Causing Chemicals. Nuclear reactors employ fission of uranium atoms to generate electricity. The fission process creates 100 to 200 radioactive chemicals not found in nature, which may damage the immune, genetic, and hormonal systems. These products include strontium, plutonium, iodine, and other carcinogenic isotopes. The only other source of these man-made chemicals is nuclear weapons explosions. Most fission products generated by reactors are contained as radioactive waste, but a fraction is emitted into air and water.

The NRC requires utilities that operate nuclear power plants to report levels of radioactive emissions into the environment each year, along with levels of radioactivity in local air, food, soil, and water. If levels fall below

government-defined "permissible limits," the NRC presumes that the public has not been harmed.

Health Studies Are Lacking. There has been a dearth of scientific, peer-reviewed studies evaluating disease rates near U.S. nuclear power plants since the first reactor began operations in 1957. Only one national study has been done. In 1990, at the insistence of Senator Edward M. Kennedy, the National Cancer Institute published data on cancer near nuclear plants. While the study concluded that there was no connection between radioactive emissions and cancer deaths, rates near many reactors rose after reactor startup. (3) Since 1990, no federal agency, including the Environmental Protection Agency and Nuclear Regulatory Commission, has undertaken any studies of disease rates near nuclear plants.

In-Body Measurements Are Lacking. The lack of health studies near American nuclear reactors is complemented by a lack of measurements of in-body levels of radioactivity for persons living near nuclear reactors. Government-supported programs to measure Strontium-90 in St. Louis baby teeth (4) and in New York City and San Francisco bones (5) were terminated in 1970 and 1982, respectively. Both measured the effects of bomb test fallout rather than nuclear power reactor emissions.

IV. SR-90 IN BABY TEETH AND CANCER RISK

RPHP Tooth Fairy Project. RPHP is addressing the shortage of information on radiation's health effects by documenting radioactivity levels in the human body and comparing them with cancer and other health patterns.

RPHP researchers are conducting **the first-ever study that measures radioactivity in the bodies of persons living near nuclear power reactors**. In 1996, RPHP launched the Tooth Fairy Project, which uses the same methodology of calculating levels of Strontium-90 (Sr-90) in baby teeth employed in St. Louis during the 1950s and 1960s. The chemical enters baby teeth through the mother's diet during pregnancy and through the mother's bones.

Sr-90 is just a marker for the 100-200 radioactive chemicals that are released in nuclear reactor operations, but it is a critical one. Like calcium, Sr-90 attaches to the bone and teeth when it enters the body, where it remains for many years due to its slow rate of decay (half-life of 28.7 years). It kills and impairs bone cells, and penetrates the bone marrow, in which the white blood cells critical to immune function are formed, making it a risk factor for all cancers. Of all man-made radioactive chemicals, Sr-90 was the one that caused the greatest health concern during the atmospheric bomb test years in the 1950s and 1960s. In 1956, Presidential candidate Adlai Stevenson remarked that Sr-90 was "the most dreadful poison in the world." (6)

To date, RPHP has collected over 3000 baby teeth, mostly from areas near reactors in California, Connecticut, Florida, New Jersey, New York, and Pennsylvania. Strontium-90 concentrations have been measured in nearly half (1463) of these teeth by Radiation Environmental Management Systems Inc., an independent laboratory in Waterloo, Canada.

The average current concentration of Sr-90 is similar to that in St. Louis in 1956, in the midst of the period of atmospheric nuclear weapons testing. Results of the Tooth Fairy Project have been published in three peer-reviewed medical journals. (7-9)

RISK FROM LOW-DOSE RADIOACTIVE NUCLIDES

The often held notion that reactions to chemicals and ionizing radiation follow a linear dose-response curve is not supported by fact. While a reaction may be proportional at high doses that impair or kill, a straight-line dose-response is not borne out at low-dose exposures, (14) nor when an insult occurs at the critical periods of fetal development, and during cell division and repair. (15)

Internal exposures to toxic chemicals and radio nuclides below the level that kills a cell is critical: such sub-lethal exposures that alter cellular function or structure and are not repaired become expressed as cancer or functional alteration. The DES daughters and sons are prime examples. Diethylstilbestrol (DES) was administered to pregnant women in the misguided idea that it would protect against fetal loss during pregnancy. Children and now grandchildren were born with anatomic and functional genital abnormalities and developed genital cancers when they reached adulthood. (16) Cells undergoing replication are hundreds of times more susceptible to radiation and magnetic effects. (17) (18)

Internal radiation may involve exposure to nuclides such as plutonium-239 and strontium-90, which stay within a body essentially for life because of long half-lives. It also involves exposure to nuclides with a short half-life such as barium-140, cobalt-57, chromium-51, cesium-134, iodine-131, and others, which release significant amounts of radiation over a period of hours to days.

Many nuclides undergo sequential decay, an ideal condition for sub-lethal damage to promote the induction of genomic instability. (19) Thus, internal decay of such isotopes as plutonium-239 and carbon-14 deliver a biological effect of infinite duration and the potential to induce genetically transmitted defects. (20) In addition, very low levels of radiation exposure demonstrate an enhanced, supra-linear effect due to the release of free radicals, resulting in functional and physiological effects, separate from genetic or mutational alteration. (21)

(22)

RADIOACTIVE STRONTIUM-90 (SR-90) IN BABY TEETH

Sr-90 is a reliably measured surrogate to determine radiological fallout because of its stability in the body and a long half-life of 28.7 years. With a half-life of 28 years, Sr-90 is persistent in the environment and in the bodies of humans. The uptake of radioactive Sr-90 follows that of calcium and becomes deposited in bones and teeth. The newborn's calcium and Sr-90 are derived from the mother's dietary intake and from her bone stores during pregnancy. (23) But Sr-90 was understood before the first atomic bomb was detonated when it was proposed by Enrico Fermi to use the bone-seeking isotope to poison the food supply of Germany during World War II. (24)

Measurements of Sr-90 deposited in human bones and teeth began after the onset of above-ground nuclear bomb tests in Nevada and were carried out by various governments, including the U.S. (25) (26) (27) An independent, comprehensive study by the Committee for Nuclear Information measured Sr-90 levels in about 300,000 baby teeth collected from children in St. Louis. (23) (28) Comparing 1949-50 births with those in 1964, Sr-90 levels increased in concentration from 0.20 to 11.03 picocuries per gram of calcium. The risk to health from this contamination and concern for the health of children worldwide led to a ban on above ground nuclear testing by the U.S. and U.S.S.R., a treaty signed by President Kennedy and Premier Khrushchev.

More recent testing followed Chernobyl releases, when the Otto Hug Institute in Germany documented a ten-fold increase in Sr-90 levels in baby teeth for children born in 1987, compared with those born in 1983-85. (29) These elevated levels are comparable to those documented in the St. Louis children at the height of above-ground nuclear bomb testing. In 1990, for unknown reasons, the U.S. Environmental Protection Agency program of reporting monthly levels of barium-140, cesium-137, and iodine-131 in pasteurized milk in 60 U.S. cities was discontinued after 33 years. (30)

REFERENCES:

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30. U.S. Environmental Protection Agency. Environmental Radiation Data. Montgomery AL, 1991.

2. The Impacts of Ionizing Radiation on Human Performance.

The DoD sponsored report by KGA Associates is hereby submitted in its entirety as Exhibit 2. Following is the abstract:

"In an effort to assess the effects of exposure to ionizing radiation on neuropsychological and physical abilities, a longitudinal study in and near Chernobyl, Ukraine was conducted.
In this report are findings from 1995 to 1998. Participants were volunteers who resided in Ukraine during and since the Chernobyl Nuclear Power Plant accident. A translated subset of the Automated Neuropsychological Assessment Metrics battery and the Gamache Physical Abilities Battery were administered to a control and three experimental groups. Controls were healthy volunteers who resided well outside of the exposed area. Eliminators were decontamination and reconstruction workers with known levels of exposure. Forestry and Agricultural workers resided and worked in contaminated areas. Analyses of 1995 - 19984-

year averaged results indicated the Eliminators were significantly impaired on all measures of neurocognitive and physical performance as compared to controls. Forestry and Agricultural workers were impaired on subsets of the neurocognitive and physical batteries. Significant correlations between levels of radiation dosage and 4-year averaged physical and cognitive performance were observed on 21 of 24 tasks for the combined exposure groups. The results appear to reflect the existence of clinically meaningful neurotoxic effects of both acute and chronic exposure to radio nuclides."[7]

These issues should be evaluated in terms of chronic exposure to low levels of ionizing radiation and acute exposures to high levels of radiation resulting from a catastrophic accident.

F. Summary of Contention One

Sufficient information has been presented to show a genuine dispute on a material issue of law or fact, including references to specific portions of the application that the petitioner disputes and the supporting reasons for each dispute, and/or identification of each asserted failure of the application to contain information on a relevant matter as required by law, as well as the supporting reasons for the petitioners belief that the application fails to contain relevant information required by law.

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[7] Gamache, Gerald L, Dennis L. Reeves, Daniel M. Levinson, and Peter I. Bidiouk. 2001. *Neurocognitive and Physical Abilities Assessments Twelve Years After the Cherynobyl Nuclear Accident.* Prepared for the Defense Threat Reduction Agency (DTRA) U.S. Department of Defense. DTRA-TR-00-14. 120 Pages.

A. Contention Number and Title:

Contention Two:

Human Reliability, Workforce Aging and Critical Skills Retention

B. Contention

The license renewal application fails to provide a Human Reliability Assessment (HRA) that analyzes the impacts of workforce aging, critical skills retention and availability, the impacts of advanced technology on human reliability, and the ability of the future workforce to adequately implement aging programs, prevent severe accidents and economic accidents, and to mitigate the effects of accidents.

C. Specific statement of the issue of law or fact to be raised or controverted

10CFR54.4 and 10CFR54.21 require evaluation of safety-related systems within the Integrated Plant Assessment (IPA).

10CFR51.53(c) requires each "applicant for renewal of a license to operate a nuclear power plant under part 54 of this chapter shall submit with its application the number of copies specified in §§51.55 of a separate document entitled "Applicant's Environmental Report -- Operating License Renewal Stage...(2) The report must contain a description of the proposed action, including the applicant's plans to modify the facility or its administrative control procedures as described in accordance with §§54.21 of this chapter."

BREDL disputes the absence of a Human Reliability Assessment in the presence of administrative controls to ensure safety in a high consequence facility.

D. Brief explanation of the basis or bases of the contention

1. Integrated safety management includes human resources as a safety system that should not be separated within an integrated safety analysis. The skills and knowledge necessary for safe operation of a nuclear power plant are as essential, if not more so, than the engineered components and structures within plants. This will remain a fact as long as "administrative safety controls" are in effect to prevent accidents from happening and to mitigate the impacts of accidents.

2. Critical skills in the nuclear power and weapons workforce are in high demand and will continue to remain in high demand. Present trends suggest supply does not meet demand. The nuclear industry is presently characterized by an aging workforce with insufficient recruitment of replacement personnel. Although efforts are underway to try to reverse this eroding of critical skill availability, the existing trend is towards a less-qualified and less-experienced workforce.

This trend is aggravated by increasing concerns regarding continued enrollment and attendance of brilliant foreign nationals at American institutions of high learning, particularly nuclear physics and engineering programs, could further erode workforce capabilities and critical skills availability. An HRA would identify how this trend could impact safety and the ability to mitigate severe accidents.

3. Human error is the direct or contributing and/or root cause of most nuclear accidents, and, vice-versa, human intervention is necessary to prevent severe accidents or mitigate the impacts. Every safety-related system and non-safety related system are dependent upon human capabilities to successfully insure safe operation of the plant; and the management of component and structural aging is equally dependent upon human resources. BREDL argues that workforce capabilities and critical skills availability are the primary limiting factor in managing Catawba and McGuire Nuclear Power Plants. Identifying, listing, and describing essential aging management programs are meaningless without the presence of a thorough HRA

4. Therefore an HRA must be conducted as part of the aging management safety analyses for the following reasons:

a. The scope of the proceeding, according to 10CFR51.53(c)(3)(ii)(L), includes

"consideration of alternatives to mitigate severe accidents." In its attempt to comply with this rule the licensee conducted "Severe Accident Mitigation Alternatives Analysis (SAMAs)" (Attachment H of the Environmental Review). In both the Catawba and McGuire SAMAs human reliability is frequently cited as an integral part of the severe accident mitigation plans:

i. Ongoing initiatives at Catawba include a "Maintenance Rule Program" that is "an administrative program to ensure that structures, systems, and components important to safety are available and capable of reliably performing their intended safety function." (Page 6 of Catawba SAMA).

ii. The Catawba Severe Accident Management Guideline (SAMG) Program "includes diagnostic tools and severe accident management guideline documents for developing strategies during an event to arrest core damage progression and mitigate fission product releases in the event of a severe accident." The fact that this program is entirely dependent upon human reliability is illustrated by the statement that "this SAMG program achieves an incremental risk reduction capability *without reliance on additional hardware and resources.*" (emphasis added). (Page 6, Catawba SAMA).

iii. Table 2.1 of the Catawba SAMA identifies "procedure changes," "PRA Based Simulator Training," "Improve Plant Personnel's Awareness of SSS importance," "Administrative controls on SSS Unavailability," and "Procedure Enhancements" as risk reduction measures already implemented at Catawba. Five of the nine alternatives implemented are almost entirely dependent upon human reliability.

b. The scope of the proceeding, according to 10CFR54.4, includes safety-related nuclear power plant systems that ensure the integrity of the reactor coolant pressure boundary, the capability to shut down the reactor and maintain it in a safe shutdown condition, and the capability to prevent or mitigate off-site radiation exposures that exceed regulatory limits.

All of these systems are dependent upon the ability of operators (10CFR55) to perform as expected and/or the reliability of personnel to properly test and monitor components and structures. For example:

i. The Ice Condenser system is an engineered safety feature but aging

management is conducted entirely through visual inspections of ice baskets and ice condenser engineering inspections[8]basket

c. The scope of the proceeding, according to 10CFR54.4(a)(2), includes non-safety related systems "whose failure could prevent satisfactory accomplishment" of these functions and capabilities. Prevention of failure of these functions and capabilities is directly and indirectly dependent upon human reliability in the monitoring and testing of components.

d. The scope includes includes systems "relied on in safety analysis or plant evaluations to "perform a function that demonstrates compliance with the Commission's regulations for fire protection, environmental qualification, ...etc. Examples here include fire brigades and environmental technicians who must follow rigorous quality assurance programs. .

e. 10CFR 54.21(a)(1) requires an integrated plant assessment (IPA) for all systems defined as being within the scope of license renewal. The IPA requires identification and listing of dozens of components and structures to be subjected to an aging management review and that are not subject to replacement based on a qualified life or specified time period.

f. 10CFR54.21(a)(3) requires that the "effects of aging will be adequately *managed* so that the intended function(s) will be maintained consistent with the CLB [Current Licensing Basis] for the period of the extended operation."

Nearly every component and structure identified as subject to aging management depends upon the reliability of humans to adequately test, monitor, and make professional judgements.

E. Statement of all appropriate facts and expert opinion to support contention

The need for a human reliability assessment to determine if Catawba and McGuire NPPs can safely operate an additional 20 years is supported by an abundance of expert documentation supporting the premise that human error is prevalent as a causal factor in accidents and as a factor

[8] Application to Renew the Operating Licenses of McGuire Nuclear Station, Units 1 & 2 and Catawba Nuclear Station, Units 1 & 2 June 2001. Appendix B. Section B.3.18. Ice Condensers.

exacerbating the impacts of accidents. The erosion of human performance and reliability capabilities in the nuclear industry makes this need even greater.

1. **Human error as a primary causal factor in nuclear reactor accidents has been recognized for decades**. For example, avoiding human error prevailed throughout the forty-two conclusions and recommendations on nuclear power accidents cited by Thompson et al (1964). [9] Experts on safety in high-consequence industrial systems at Sandia National Laboratory have stated:

> "Analysis of major industrial accidents such as Three Mile Island, Chernobyl, and Bhopal have revealed that these incidents were not attributable to a single event or direct cause, but were the result of multiple factors that combined to create a condition ripe for an accident. In each case, human error was a critical factor contributing to the accident. Consequently, many authors have emphasized the need for greater appreciation of systemic factors and in particular, human activities." [10]

BREDL hereby submits Exhibit 3, Chapters 7 and 9 as an expert analysis of these facts.

2. **The prevalence of human error as a causal factor in accidents and as a factor exacerbating the impacts of accidents is well documented:**

a. One result of NRC efforts in the 1990's to "address limitations identified in current HRA [Human Reliability Assessment] approaches" was the development by Sandia National Laboratory for a new HRA called "A Technique for Human Events Analysis," called ATHEANA. Bley et al (1999) provided background on the need for ATHEANA:

"The record of significant incidents in nuclear power plant operations shows a substantially

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[9] Thompson, T.J., and J.G. Beckerly (eds). *The Technology of Nuclear Reactor Safety. Volume I. Reactor Physics and Control.* The M.I.T. Press. Copyright 1964. Pages 701-704.

[10] Forsythe, Chris, and Eric Grose. 1997. *Human Factors in High Consequence Manufacturing Systems.* Statistics and Human Factors Department, Sandia National Laboratory. SAND-97-2622C.

different picture of human performance than that represented by human failure events modeled in PRAs. The latter typically represent failures to perform required procedure steps. In contrast, human performance problems identified in real operational events often involve operators performing actions that are not required for accident response and, in fact, worsen the plant's condition (i.e., errors of commission). Further, accounts of the role of operators in serious accidents, such as those that occurred at Chernobyl 4 [2,3] and Three Mile Island 2 (TMI-2) [4], frequently leave the impression that the operator's actions were illogical and incredible. Consequently, the lessons learned from such events often are perceived as being very plant-specific or event-specific."

"However, there is increasing evidence that there may be a persistent and generic human performance problem that was revealed by TMI-2 (and Chernobyl) but not 'fixed: errors of commission involving the intentional operator bypass of engineered safety features (ESF)."[11]

b. Brookhaven National Laboratory is another recipient of NRC funding for analysis of the human factor. According to one report regarding control room modernization:

Changes in automation can have a major effect on the operator's role, defined as the integration of the responsibilities that the operator performs in fulfilling the mission of plant systems and functions. Since automation has been predominately technology driven, changes in automation often fail to result in a coherent role for operators."

"Automated systems have generally been designed with inadequate communication facilities which make them less observable and may impair the operator's ability to track their progress and understand their actions. In one case this problem led to operators defeating or otherwise circumventing a properly automated system because they believed it was malfunctioning."[12]

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[11] Bley, et al. Philosophy of ATHEANA. SAND-99-0702C.

[12] O'Hara, John, Bill Stubler (Brookhaven National Lab), and Joel Kramer (NRC). 1997. *Human Factors Considerations in Control Room Modernization: Trends and Personnel*

c. Sandia also conducted an assessments that determined there is a higher likelihood of human error during NPP low power and shutdown mode:

"Human error with a reduced water inventory is a key contributor to core damage frequency (CDF)" during LPSD, and a limitation in assessing probabilistic risk in these situations is "human reliability during transitions and other shutdown activities."[13]

3. The ongoing erosion of America's nuclear workforce capabilities and availability of critical skills is equally well documented. Three examples are provided to support this contention:

a. On February 28, 2001 NRC Chairman Richard Meserve described the "Human Capital" situation to the Vice President of the United States as follows:

"The NRC's ability to fulfill its mission is critically dependent upon the expertise of its staff and contractors. As with many Federal agencies, it is becoming increasingly difficult for NRC to hire personnel with the knowledge, skills, and abilities to conduct the safety reviews, licensing, and oversight actions that are essential to our safety mission. In some important offices, nearly 25 percent of the staff are eligible to retire today. Moreover, the number of individuals with the technical skills critical to the achievement of our safety mission is rapidly declining in our Nation and our educational system is not replacing them."[14]

Chairman Meserve went on to offer potential remedies such as modifying conflict-of-interest

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Performance Issues. BNL-NUREG-64193. Sponsored by the Nuclear Regulatory Commission.

[13] Camp, et al. 1999. Perspectives on Low Power and Shutdown Risk. Sandia National Laboratory. SAND 99-3114C. Sponsored by the Nuclear Regulatory Commission.

[14] February 28, 2001 letter from Richard A. Meserve, NRC Chairman, to the Vice-President of the United States. Available on ADAMS.

provisions regarding Department of Energy contractors, increasing NRC staff salaries, hiring consultants from the pool of NRC retirees at full pay, and funding University training programs:

"A recent blue-ribbon engineering panel reporting to the Department of Energy has identified a significant decline in the number of nuclear-related academic programs. Moreover, many universities are contemplating the shut-down of research reactors, limiting the opportunities for students and researchers. Congress could help to reverse this trend by funding academic fellowships to attract engineering students, by sustaining important research facilities, and by enabling the NRC to establish a training program to address shortages of individuals with critical safety skills."[15]

b. The Department of Energy's (DOE) Argonnne National Laboratory (ANL) is a leading scientific R&D resource of the nuclear power industry. Operated by the University of Chicago, it serves as the lead laboratory, in collaboration with Idaho National Engineering and Environmental Laboratory, for nuclear reactor technology for DOE's Office of Nuclear Energy, Science, and Technology.[16]

Argonne National Laboratory believes that nuclear energy "must contribute increasingly to the world's energy supply if major environmental goals are to be met."[17] The caveat behind this perception is that there is "the need for a major U.S. initiative in nuclear technology R&D."[18] According to the most recent ANL Institutional Plan, "the U.S. nuclear technology infrastructure, which once led the world, has been eroded seriously and couuld be lost entirely if present trends continue."

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[15] Ibid.

[16] Argonne National Laboratory Institutional Plan. FY 2001-2006. October 2000. Page 15.

[17] Ibid. Page 51.

[18] Ibid. Page 85.

Argonne's nuclear technology program goals and objectives include "maintaining a set of technical capabilities in nuclear science and technology–including both expertise and infrastructure–sufficiently broad and deep to address a full range of national needs...maintain a complete core competency in nuclear technologies so that a nuclear option remains available to the United States for the long term...conduct educational and training activities for U.S. and international participants, to improve knowledge of nuclear technology worldwide and to ensure a high level of capability in the staffs of safety oversight and regulatory agencies."[19]

c. **The Chiles Commission** was established to review the nuclear weapons workforce and determine needs and priorities. The Commission concluded in its 1999 report that, "large numbers of workers are reaching retirement and a new generation of workers must be hired and trained in order to preserve essential skills."[20]

3. The licensee's operational history indicates that most incidents, occurrences, and accidents have human error as a direct or contributing cause. Three events out of hundreds at Catawba and McGuire are cited as examples:

a. Significance: TBD Feb 16, 2001
Identified By: NRC
Item Type: AV Apparent Violation
Failure to Promptly Identify and Correct the Unit 1 Residual Heat Removal System Water Hammer Condition
An apparent violation of 10 CFR 50, Appendix B, Criterion XVI was identified for the failure to identify a root cause and establish effective corrective actions to prevent repetitive water hammer events in the Unit 1 residual heat removal (ND) system which have caused the repeated failure of snubbers on supports 1-R-ND-0226 and 1-R-ND-0596. (Section 40A2.b.(2).2)
Inspection Report# : 2001003*(pdf)*

b. Significance: G Mar 30 2001

[19] Ibid. Page 51.

[20] Commission on Maintaining United States Nuclear Weapons Expertise. *Report to the Congress and Secretary of Energy Pursuant to the National Defense Authorization Acts of 1997 and 1998*. March 1, 1999

Identified By: NRC
Item Type: FIN Finding
Failed to Demonstrate Performance of the Station Drinking Water System as Backup Cooling Water to the Unit 1 and 2 A Train Charging Pumps
The licensee failed to demonstrate that the performance or condition of the station drinking water system, a risk-important system that provides backup cooling water to the Unit 1 and 2 A train charging pump motors and bearing oil coolers, was being effectively controlled through the performance of appropriate preventive maintenance (including surveillance activities). This resulted in a failure to recognize and correct a degraded system pressure condition, until it was identified by the inspectors. The degraded pressure condition was determined to be of very low safety significance because an analysis performed by the licensee demonstrated that the backup function to cool the charging pumps and motors would have been provided at the degraded pressure (Section 1R12.2).
Inspection Report# : 2000006*(pdf)*

c. Significance: G Jun 24, 2000
Identified By: Licensee
Item Type: NCV NonCited Violation
Failure to Provide Adequate Procedures for Performing Maintenance on Safety-Related Sump Pump Level Switches
Residual heat removal and containment spray pump room sump level alarm function was lost for several months up to February 2000 due to inadequate maintenance procedures associated with sump level switch calibrations. This issue was characterized as a non-cited violation of Technical Specification 5.4.1 and was determined to be of very low safety significance due to the availability of other emergency core cooling system leak detection methods (Section 4OA3.2).
Inspection Report# : 2000003*(pdf)*

4. Recently published research points to a potential link between chronic exposure to radiation and a reduction in neurocognitive abilities. See Exhibit 2.

F. Summary.

BREDL has presented, as required by 10CFR2.714 "sufficient information to show a genuine dispute on a material issue of law or fact." BREDL has not cited "references to specific portions of the application that the petitioner disputes" because the reason for the dispute is the "failure of the application to contain information on a relevant matter as required by law." The "supporting reasons for the petitioner.s belief that the application fails to contain relevant information required by law" is more than adequately defined and presented to be accepted as a contention in a hearing.

A. Contention Number and Title:

Contention Number Three: Steam Generator Aging Management Program

B. Contention

The aging management program for steam generators and associated components such as steam generator tubes is insufficient and incomplete, and does not assure safe operations that prevent design basis and severe catastrophic accidents. In addition, the DBA frequency for steam generator tube rupture is grossly underestimated

C. Specific statement of the issue of law or fact to be raised or controverted

The licensee's aging management program for Steam Generators is incomplete (10CFR54.13) and does not assure safe operation (10CFR54.21) . Licensee program to ensure the prevention of steam generator degradation is insufficient both in practice and in the renewal application.

Futhermore, the licensee's estimates of a Design Basis Accident involving steam generator tube rupture is

D. Brief explanation of the basis or bases of the contention;

1. Steam generators are large components which convert water into steam from the heat produced in nuclear reactor cores; and fall within the category of Reactor Vessel, Internals, and Reactor Coolant System in NUREG 1800 (Chapter 3.1) and NUREG 1801 (Part 4). Each steam generator consists of numerous sub-components.

2. The licensee identified (Table 3.1.1, Pages 3.1-21 to 3.1-24) twenty-two (sub)component types in its aging management review results and wrote that each component functions to "maintain mechanical pressure boundary integrity" (Page 3.1.26). Loss of integrity could lead to accidents that result in unacceptable radiation exposure to the off-site public, economic losses due to shutdown, and loss of electrical supply to the region.

3. There are four steam generators in each licensee reactor, and their sub-components are subject to aging management analysis in accordance with 10CFR 54.4, 10CFR54.21(a)(1), and 10CFR54.21(a)(3). The aging management analysis must adhere to 10CFR**54.13**(a) by providing

complete and accurate information.

4. Each steam generator consists of thousands of steam generator tubes considered highly vulnerable to corrosion and deformation. These tubes must be closely monitored and problems corrected to avoid a rupture of one or more tubes. Two of the fifteen known steam generator tube rupture occurrences in U.S. NPPs occurred at McGuire 1.[21]

The licensee's overall program for managing aging of steam generator tubes is encompassed within three aging management programs:

a. The scope of the *Steam Generator Surveillance Program* includes "all steam generator tubes (including plugs and sleeves) in each steam generator and internal support structures."[22] Because the description of this program in Appendix B, Part B.3.31-3 is simplistic, overly brief, and contains numerous discrepancies and omissions (see Part E), compliance with 10CFR54.13 and subsequently 10CFR54.21(a) is being disputed by BREDL.

b. The *Alloy 600 Aging Management Review* is a proposed program to rank susceptibility to primary water stress corrosion cracking, ensure that nickel-based alloy locations are adequately inspected by the *Inservice Inspection Plan* or other programs. However, the licensee states that the review will be complete by the end of the initial 40-year license period[23] and as such does not provide the assurance required by 10CFR54.21.

c. The *Chemistry Control Program* is for managing "loss of material and/or cracking of components exposed to borated water, closed cooling water, fuel oil, and treated oil environments" and is described as a mitigation program.[24] The licensee failed to identify past problems with

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22. Application to Renew the Operating Licenses of McGuire Nuclear Station, Units 1 & 2 and Catawba Nuclear Station, Units 1 & 2 June 2001. Appendix B. Aging Management. Part B.3.31 Steam Generator Surveillance Program.

23 Ibid. Page B.3.1-1.

24 Ibid. Page B.3.6-1.

chemistry control prevalent throughout the industry and the efforts required to prevent recurrence.

5. The licensee has in practice sought and obtained "relief" from meeting regulatory requirements and industry standards for pre-service inspection of numerous steam generator subcomponents (See E). This practice resulted in the failure to develop a baseline for monitoring aging of these parts. The licensee failed to identify these issues, a violation of 10CFR54.17.

E. Statement of all appropriate facts and expert opinion to support contention

1. Background on Steam Generators and Steam Generator Tubes

a. Steam generators are large components which convert water into steam from the heat produced in nuclear reactor cores. According to the NRC:

"These devices can measure up to 70 feet in height and weigh as much as 800 tons. Inside the steam generators, hot radioactive water is pumped through thousands of feet of tubing–each steam generator can contain anywhere from 3,000 to 16,000 tubes, each about three-quarters of an inch in diameter–under high pressure to prevent it from boiling. That water flowing through the inside of the tubes then heats non-radioactive water on the outside of the tubes This produces steam that turns the blades of turbines to make electricity. The steam is subsequently condensed into water and returned to the steam generator to be heated once again."

These tubes have an important safety role because they constitute one of the primary barriers between the radioactive and non-radioactive sides of the plant. For this reason, the integrity of the tubing is essential in minimizing the leakage of water from the two 'sides' of the plant. There is the potential that if a tube bursts while a plant is operating, radioactivity from the primary coolant system–the system that pumps water through the reactor core–could escape directly to the atmosphere in the form of steam. However, such a rupture has not occurred sine

March 14, 1993, when a tube burst at Palo Verde 2 in Arizona."[25]

Subsequent to publishing this information a tube rupture at Indian Point 2 caused that reactor to shut down and initiated an extensive investigation. *No mention of this event or any other steam generator tube rupture exists in the application.*

b. "Steam generator tubes have proved to be especially susceptible to corrosion," and the primary problem today in PWRs is "stress corrosion cracking of the tube." Stress corrosion cracking is difficult to predict and detect and "there is a need for better methods to both detect and to size" cracks produced by this mechanism.." as well as a need for better technology "to predict whether cracks will grow to unacceptable dimensions during future cycles of plant operations."[26] *The licensee made no mention of these difficulties and associated uncertainties.*

c. Stress corrosion cracking is the "principal degradation model leading to tube plugging in the U.S. and worldwide."[27]

d. In 1995 the NRC wrote that:

- "Both the NRC and the industry have identified the reliable detection and sizing of circumferential cracks in steam generator tubes as a technical issue of concern."
- Steam generator tube ruptures represent a "failure of one of the principal fission product boundaries and present a pathway for primary system activity release to the environment..."and
- "Inspection practices should furnish assurance that steam generator tube degradation will be

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[25] NRC Technical Issues Paper and Fact Sheets. TIP:27. *Steam Generator Tube Issues.* Originally at NRC Office of Public Affairs Technical Issues Index, http://www.nrc.gov/OPA/gmo/ Available on ADAMS as part of response to FOIA 2001-256.

[26] SAND 2000-1936C. Page 6. Powers, D.A. Material Issues in Modern Reactor Safety. Sandia National Laboratory.

[27] ANL/ET/CP 91433. Overview of Steam Generator Tube Degradation and Integrity Issues. D.D. Diercks. Et al. October 1996.

reliably detected" so that the potential for rupture is maintained at an acceptably low level.[28]

e. The NRC wrote in its 1996 version of the GALL that steam generator tubes are susceptible to additional aging mechanisms such as attrition, wear, ...[29]

f. Dr. Joram Hopenfeld, a recently retired NRC staffer, began writing "Differing Professional Opinions" regarding steam generator tubes in December of 1991, and subsequently issued DPOs (and addendums) in March 1992, September 1992, September 1998, April 2000, and April 2001. The series of documents available on ADAMS that are introduced as evidence are referenced as Attachment 1-1. It is useful to provide excerpts from the most recent DPO:

" It is now almost 10 years since I originally raised several serious safety issues concerning the NRC practice of permitting excessively degraded steam generators tubes to remain in service during plant operations. This practice while benefitting the nuclear industry, has had a serious negative potential impact on public safety. After many and continuing attempts by NRC management to ignore these DPO issues, they remain unresolved. As demonstrated by the Indian Point 2 (IP2) accident, excessively degraded tubes continue to threaten public safety.

"During the past ten years, the NRC has expended inordinate resources on my DPO safety issues and has publically claimed that they have been properly addressed. The new ACRS findings, NUREG-1750, clearly indicate that the staff contentions were flawed and misleading, and that the allocated resources have been wasted."

"The ACRS had concluded last November that the staff position on the issues raised by the DPO is indefensible. Accordingly, the Executive Director for Operations, EDO, was requested to resolve these issues and report the outcome to the ACRS. Instead, the EDO

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[28] NRC Generic Letter 95-03. Circumferential Cracking of Steam Generator Tubes. April 28, 1995.

[29] GALL 1996. Page 14A. Cited in:

merely instructed the divisions of RES and NRR to draft a new action plan and closed the DPO. Closing the DPO without specifying how it will be resolved is a clear violation of Management Directive (MD) 10.159(C). The EDO's latest action compounds previous violations of MD 10.159, making a sham of the entire process of encouraging employees to raise safety concerns. The NTEU union filed a grievance on my behalf to keep the DPO open until it is resolved.

The transcripts from the ACRS hearings and the following quotations from NUREG-1750 clearly demonstrate the poor state of knowledge at the NRC regarding steam generator safety issues.

1. ' the **staff has not** adopted **a technically defensible** position on the choice of iodine spiking factor to be used on the analysis of design for compliance with requirements of 10 CFR Part 100 or General Design Criteria 19.'

2. 'The **staff need to develop a defensible analysis** of the uncertainties in its risk **assessment**, including uncertainties in its assessments of human error probabilities" (during design basis accidents.)

3. 'The **staff has not** developed **persuasive arguments** to show that steam generator tubes will **remain intact** under the conditions of **risk-important accidents** which the reactor coolant remain pressurized.'

4. 'The Ad-Hoc Subcommittee found that the **staff did not have a technically defensible understanding** of these processes to assess adequately the potential for **progression of damage of steam generator tubes.'**

5. 'The Ad-Hoc Subcommittee did not feel that the staff has **developed an adequate understanding** of how movements of the tube support plate during an event could damage the tubes.'

6. 'The Subcommittee did not attempt to reach conclusions concerning occasions when staff granted exemptions to these criteria (1& 2 V) except to note that these exemptions **should**

have been accompanied by more complete risk analysis.'

7. 'The databases for 7/8" tubes **need to be greatly improved to be useful.'**

8. 'This issue (tube shearing during depressurization), at the **current level of understanding cannot be used** to judge the adequacy of the alternative repair criteria described in **GL-95-05.'**

9. 'the issue of the possible evolution of severe accidents to involve **gross failure** of **steam generator tubes** and bypass of the containment **is not yet resolved.'**

Steam generators were originally sold to the utilities with the understanding that they would operate acceptably within design parameters for the lifetime of the plant. Because of inadequate and improper material selection, this expectation has never been fulfilled and some steam generators have been replaced after only a few years of service. U.S. plants alone have experienced 11 steam generator tube failure accidents, which can be traced to poor design and lack of meaningful NRC oversight. Additional, and possibly catastrophic, steam generator tube failure accidents can be expected in the future since many nuclear power plants will be relicensed for another 20 years.

The nuclear industry, however, has done essentially nothing to seriously address the safety issue. Licensees have demonstrated that their main goal is to continue using severely degraded steam generators as long as they want to do so. The NRC has been unwilling to insist that safety take priority over economics.

The NRC practices regarding steam generators contributed significantly to the recent IP2 accident. Fortunately this accident did not have significant safety consequences, it was, however, a serious precursor to the type of accidents which are described by the DPO. The NRC takes the unacceptable position that if the DPO accidents have not occurred they will not occur in the future."[30]

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g. A few weeks after Dr. Hopenfelds last DPO, David Lochbaum of the Union of Concerned Scientists testified before the Clean Air, Wetlands, Private Property, and Nuclear Safety Subcommittee of the United States Senate Committee on Environment and Public Works.[31] In regard to Steam Generator Tube ruptures, Lochbaum stated:

"The NRC's Advisory Committee on Reactor Safeguards (ACRS) issued a report in February 2001. The ACRS substantiated many of Dr. Hopenfeld's concerns. For example, the ACRS concluded:

'The techniques [used to look for cracked steam generator tubes] are not nearly so reliable for determining the depth of a crack, and in particular, whether a crack penetrates through 40% of the tube wall thickness.' [NRC's regulations do not allow a nuclear plant to start up with any steam generator tube cracked more than 40 percent of its wall thickness, but the methods used to inspect the tubes for cracks cannot reliably determine the depth of cracks.]

'The NRC staff acknowledged that there would be some possibility that cracks of objectionable depth might be overlooked and left in the steam generator for an additional operating cycle.' [Exactly what actually happened at Indian Point 2 to cause last year's accident.]

'Both the [NRC] staff and the author of the DPO [Dr. Hopenfeld] agree that the alternative repair criteria' [used by the NRC staff to allow nuclear plants to continue operating with steam generator tubes known to be cracked] 'increase the probability of larger primary-to-secondary flows during the MSLB [main steam line break] and SGTR [steam generator tube rupture] accidents.'

'The [ACRS] also finds that this contention of the DPO [namely, that an

[31] http://www.ucsusa.org/energy/ts_reactsafe.html

accident at a nuclear plant with cracked steam generator tubes could cause those tubes to completely break] has merit and deserves investigation.'

'This seems to be a plausible contention [that an accident at a nuclear plant with cracked steam generator tubes could widen the cracks and result in larger leakage], and the staff has not produced analyses or test results to refute it.'

'The [ACRS] concluded that the issue of the possible evolution of severe accident to involve gross failure of steam generator tubes and bypass of the containment is not yet resolved ... [and] that the issue needs consideration regardless of the criteria adopted for the repair and replacement of steam generator tubes.'

'Data available to the [ACRS] suggest that the constant probability of detection [of cracked steam generator tubes] adopted by the NRC staff is nonconservative for flaws producing voltage signals less than about 0.7 volts.' [In other words, the NRC staff assumes that methods used to find cracked tubes are much better than the data shows them to be.]

'The [ACRS] was unable to identify defensible technical bases for the [NRC] staff decisions to not consider the correlation of the iodine spiking factor with initial iodine concentration [when evaluating the potential offsite radiation dose consequences from accidents involving cracked steam generator tubes].'

'The [ACRS] found that the [NRC] staff did not have a technically defensible understanding of these processes to assess adequately the potential for procession of damage to steam generator tubes.' [In other words, the NRC staff has no sound basis for arguing that one broken tube will not cascade and

cause the failures of other tubes.]

'The [NRC] staff has not developed persuasive arguments to show that steam generator tubes will remain intact under conditions of risk-important accidents in which the reactor coolant system remains pressurized. The current analyses dealing with loop seals in the coolant system are not yet adequate risk assessments.'

'In developing assessments of risk concerning these design basis accidents, the [NRC] staff must consider the probabilities of multiple tube ruptures until adequate technical arguments have been developed to show damage progression is improbable.'[In other words, the risk studies to date, which only consider failure of a single tube, may understate the true risk and therefore should not be relied upon.]

The concerns raised by Dr. Hopenfeld are extremely important safety issues. As the ACRS stated:

'Steam generators constitute more than 50% of the surface area of the primary pressure boundary in a pressurized water reactor.'

'Unlike other parts of the reactor pressure boundary, the barrier to fission product release provided by the steam generator tubes is not reinforced by the reactor containment as an additional barrier.'

'Leakage of primary coolant through openings in the steam generator tubes could deplete the inventory of water available for the long-term cooling of the core in the event of an accident.'"

2. The licensee's steam generator aging management program actually involves five major aging management programs:

- Chemistry Control Program
- Inservice Inspection Plan
- Alloy 600 Aging Management Review
- Fluid Leak Management Program
- Steam generator surveillance program

Deficiencies exist in at least three of the program descriptions in the application as they pertain to steam generators, and these deficiencies are primarily errors of omission:

a. The application states that "the purpose of the *Steam Generator Surveillance Program* is to provide comprehensive examinations of the steam generator tubes to ensure that degradation is identified and corrective actions are taken prior to exceeding allowable limits. The *Steam Generator Surveillance Program* is a condition monitoring program that is credited with managing loss of material and cracking of Alloy 600 and 690 steam generator tubes...The scope of the *Steam Generator Surveillance Program* includes all steam generator tubes (including plugs and sleeves) in each steam generator and internal support structures."[32] The program is described as "equivalent," not equal, to the program described in NUREG 1723.

Generic issues that were not identified within Table 3.1.1 of the Technical Review, Appendix B, Part B3.31 "Steam Generator Surveillance Program," or the USFAR include:

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[32]. Application to Renew the Operating Licenses of McGuire Nuclear Station, Units 1 & 2 and Catawba Nuclear Station, Units 1 & 2 June 2001. Appendix B. Aging Management. Part B.3.31 Steam Generator Surveillance Program.

i. an aging management program applicable to either the existing steam generator or the replacement steam generator in Catawba 2;

ii. aging of steam generator tube materials due to "deformation due to corrosion at tube support plate intersections," which was identified by the NRC in the SRP.[33]

iii. the various cracking initiation mechanisms in steam generator tubes, i.e. stress corrosion cracking within the broader category of "cracking;"

iv. Further evaluation of Alloy 600 steam generator tubes, repair sleeves and plugs; steam generator shell assembly, and other steam generator components as recommended by the NRC in Table 3.1-1 of the SRP.

b. The *Alloy 600 Aging Management Review* is a proposed program to rank susceptibility to primary water stress corrosion cracking, ensure that nickel-based alloy locations are adequately inspected by the *Inservice Inspection Plan* or other programs. However, the licensee states that the review will be complete "by" the end of the initial 40-year license period[34] and as such does not provide the assurance required by 10CFR54.21 to identify its aging management program within the license application. A "review" is only a part of a "program."

c. The *Chemistry Control Program* is for managing "loss of material and/or cracking of components exposed to borated water, closed cooling water, fuel oil, and treated oil environments" and is described as a mitigation program.[35] The licensee failed to identify past problems with chemistry control prevalent throughout the industry and the efforts required to prevent recurrence.

3. Deficiencies in the licensee's operating experience warrant further scrutiny of the steam generator aging program:

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[33] NUREG 1800, Table 3.1-1, Page 3.1-19.

[34] Ibid. Page B.3.1-1.

[35] Ibid. Page B.3.6-1.

The licensee provides a minimal background on operating experience related to steam generator issues, only citing the year of steam generator replacement and some observations on aging of tubes. Incidents not included in the discussions of operational history include:

a. Two of the fifteen known steam generator tube rupture occurrences in U.S. NPPs occurred at McGuire 1.

b. In June 1997 McGuire 2 was shut down "because of an increasing primary-to-secondary leak.".

c. Steam generators were replaced after less than 20 years of operation in 3 of the 4 reactors, yet no reason was provided for this major refurbishment. The abbreviated life span of the first steam generators indicates an inability to implement a strong and durable aging management program.

d. When the licensee replaced the Catawba 1, McGuire 1, and its steam generators it failed to conduct pre-service examinations on numerous subcomponents until after it installed the new generators. According to the NRC, "the preservice examinations were not performed during manufacturing or prior to installation of the SGs. Instead, the licensee performed onsite preservice examination of the SGs after installation."

As a result the preservice examinations could not achieve the 100% examination volume required by industry standards. On June 4, 2000 the licensee requested relief from preservice inspection requirements of steam generators that were then 2-4 years old. Nearly a year passed before the NRC acquiesced and granted the relief based upon the rational that following codes was not economically feasible.

F. Summary.

BREDL has shown sufficient information to show a genuine dispute on a material issue of law or fact, including references to specific portions of the application that the petitioner disputes and the supporting reasons for each dispute, and/or identification of each asserted failure of the application to contain information on a relevant matter as required by law, as well as the supporting reasons for the petitioners belief that the application fails to contain relevant information required by law.

Contention Number and Title:

Contention Four: Aging Management of Ice Condensers

B. Contention:

The aging management programs associated with the Catawba and Mcguire Ice Condenser systems are insufficient to assure safe operations and prevent design-basis and severe accidents.

C. Specific statement of the issue of law or fact to be raised or controverted

10CFR51.53(c)(3)(ii)(L) requires "consideration of alternatives to mitigate severe accidents," which the licensee submitted as part of its Environmental Reports (ER).

10CFR51.53(c)(3) requires the ER to "contain a consideration of alternatives for reducing adverse impacts, as required by §§51.45(c), for all Category 2 license renewal issues in Appendix B to subpart A of this part."

Aging management and time-limited aging management programs of numerous Ice Condenser systems and components are required to comply with 10CFR 54.4, 10CFR54.21(a)(1), and 10CFR54.21(a)(3) in order to insure safe operations and prevent design basis and severe accidents.

Brief explanation of the basis or bases of the contention;

1. Catawba and McGuire NPPs constitute four of the ten existing Pressurized Water Reactors with ice condenser containment systems. These ice-condenser containment systems are the most vulnerable among all U.S. NPPs to loss of containment accidents.

2. The licensee's aging management programs for ice condenser systems and components[36] does not comply with 10CFR54.21(a) because it is incomplete and inaccurate (10CFR54.17) and fails to provide reasonable assurance that aging management will allow these systems to function as designed when necessary and prevent a catastrophic release of fission products to our environment.

3. The licensee's SAMA analysis is incomplete because it fails to incorporate new and extensive information regarding ice condenser vulnerabilities. In its "analysis of potential containment-related SAMAs," the licensee failed to even identify potentially dominant failure modes for a severe accident.

4. The licensee's operational experience shows a history of deficiencies and the application was incomplete and inaccurate about the extent and depth of deficiencies in the operational record.

D. Statement of all appropriate facts and expert opinion to support contention

1. The experts joke about ice condenser containment:

"I just wonder if ICE condensers had some peculiarity about them that I didn't know about other than vulnerable containment.

(Laughter)

Mr. Kress: You were reading my mind.

Mr. Powers: I saw you grinning over there."

Official Transcript of dialogue between Advisory Committee on Reactor Safeguards' members Mr. Dana M. Powers and Thomas S. Kress at the ACRS February 2, 2001 Meeting, in reference to the proposed use of Plutonium/MOX fuel in Catawba and McGuire NPPs.

2. *Assessment of the DCH Issue for Plants with Ice Condenser Containments*

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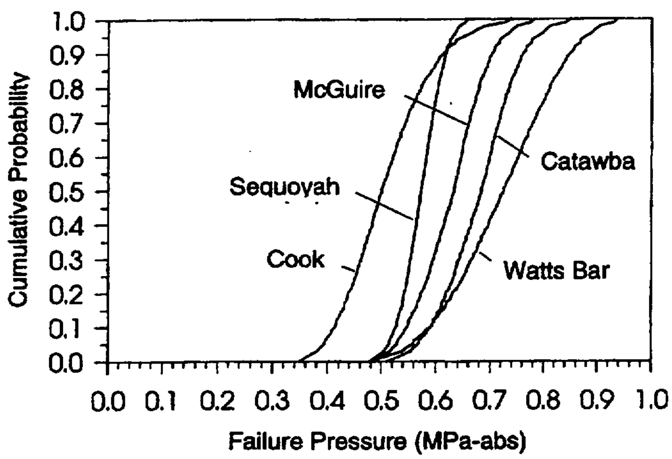
[36] Programs cited in the application are AC powered igniters, containment buildings, Ice beds, containment spray system, ice condenser refrig. Page 2-3.18, Chemistry control, Fluid Leak Management.

(NUREG/CR-6427. SAND99-2253)[37] is a voluminous NRC sponsored study by Sandia National Laboratory published in April 2000, and therefore contains information that is considered new and relevant. While this report is far too in depth and voluminous to cite at length, two excerpts are provided:

a. From: Chapter 6. Quantification of Containment Fragility. Page 102.

> 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.



b. Figure 6.1 showing Fragility Curves for all Westinghouse Ice Condenser NPPs:

[37] Pilch, M.M., K.D. Bergeron, and J.J. Gregory. April 2000. Assessment of the DCH Issue for Plants with Ice Condenser Containments. Sandia National Laboratories. Albuquerque NM. Prepared for Division of Systems Analysis and Regulatory Effectiveness, Office of Nuclear Regulatory Research. US NRC.

c. From Chapter 8.0 Summary and Recommendation, Page 124.

A plant-specific evaluation of the CET showed that all plants, except McGuire, had an early failure probability (given core damage) within the range of 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 the difference.

d. The licensee failed to even reference this landmark report in its Severe Accident Mitigation Alternative Analyses (Section 8, References), and searches of the 626-page application and Appendix B of the application for "Pilch" and "NUREG/CR-6427" yielded no information.

e. BREDL requests that this document be introduced as an Exhibit by the Panel as a central point of dispute in this proceeding. However, the size of the document (348 pages, 24.5 MB in ADAMS TIFF File format) makes it prohibitive for BREDL to copy and distribute this. Instead it is being placed on a CD-ROM along with other references as part of BREDL's submission.

2. **The issue of ice condensers raised by Pilch et al was best summarized in a November 2000 report by Dr. Edwin S. Lyman of the Nuclear Control Institute, excerpted in part here:**

"Vulnerabilities of Ice Condenser Containments

Nuclear power plants in the U.S. are required to have robust reactor containment buildings. The main purpose of these structures is to prevent the release of large quantities of radioactive materials in the event of a reactor core meltdown. In the aftermath of the 1986 Chernobyl accident in the former Soviet Union, the nuclear industry maintained that such a severe accident could never happen in the U.S. because U.S. reactors, unlike the Chernobyl reactor, were equipped with containments.

However, not all containments offer equal protection. Most pressurized-water reactors (PWRs) in the U.S. have "large dry" containments, which are typically massive concrete structures with walls several feet thick. Catawba and McGuire, on the other hand, are

among a handful of PWRs worldwide with "ice condenser" containments. These are typically thin steel shells that have only half the volume and failure pressure of large dry containments. To compensate for the reduced strength of their containment buildings, ice condenser plants are equipped with "ice beds." These consist of baskets filled with blocks of ice that are supposed to cool and condense steam flowing past them during a core-melt accident, reducing the threat that the containment will become overpressurized and rupture from the rapid generation of steam.

However, even if the ice condensers do work as they are supposed to (which in itself is a questionable proposition), containment failure can still occur as a result of the combustion of hydrogen gas, which would be generated in large quantities during severe accidents when the metal cladding on fuel rods reacts with coolant water. During the Three Mile Island 2 (TMI-2) accident in 1979, a large amount of hydrogen was released to the containment and burned, although the pressure increase did not lead to rupture of TMI-2's large dry containment. The ice condensers not only cannot reduce the risk of hydrogen combustion but also can actually increase it, because they divide the containment volume into small compartments where hydrogen gas can more readily reach explosive concentrations.

The seriousness of this issue is clear from the following data on the strength of containment buildings. The pressure that can be generated in the containment from hydrogen combustion can typically reach a value of about 110 pounds per square inch (psi). The average failure pressure of U.S. large dry containments is around 113 psi, whereas for ice condenser containments it is around 63 psi. Therefore, hydrogen burns can easily overpressurize and rupture ice condenser containments.

For this reason, after the TMI-2 accident, NRC required that ice condenser plants install hydrogen igniters, which are operator-initiated, AC-powered devices that are designed to burn hydrogen at a controlled rate before it reaches an explosive concentration.

However, the risk of hydrogen explosions in ice condensers has not been eliminated entirely by this requirement, since the hydrogen igniter systems now in use require AC power to operate. Therefore, in the event of a simultaneous loss of both off-site and on-site AC power supplies, known as a station blackout (SBO), hydrogen control is lost.

Earlier this year, the Nuclear Regulatory Commission (NRC) released a report that analyzed the risk of containment failure during severe accidents at reactors with "ice condenser" containments. The report, entitled Assessment of the DCH [Direct Containment Heating] Issue for Plants with Ice Condenser Containments, NUREG/CR-6427, finds that "no ice condenser plant is inherently robust to all credible hydrogen combustion events in a SBO accident." It also concludes that "ice condenser plants are at least two orders of magnitude [one hundred times] more vulnerable to early

containment failure than other U.S. PWRs" as a result of hydrogen explosions during core melt accidents. This study, which was performed by Sandia National Laboratories (SNL) in Albuquerque, calculated that for accidents in which the hydrogen igniters were not available, such as SBOs, the probability that the containment would rupture as a result of hydrogen combustion is 34% for Catawba and 58% for McGuire. Using the same methodology, previous NRC studies found that the risk of containment failure at large dry containments is less than 0.1%.

SNL found that certain SBO accidents --- namely, those in which the reactor coolant system remains at high pressure at the time that the reactor vessel is breached by molten fuel --- the probability of early containment failure as a result of detonation of pre-existing hydrogen is nearly 100% for both Catawba and McGuire. This means that if one of these sequences were to occur, there would be little difference between the ice condenser plants and nuclear plants without containments like Chernobyl.

NRC and the nuclear industry continue to argue that accidents as severe as an SBO are so unlikely that the weakness of ice condensers is not a high-priority concern. However, an SBO actually occurred at the Vogtle plant in Georgia in 1990, during which the plant lost all off- and on-site power supplies for 35 minutes. Other plants have come quite close to an SBO. For instance, in 1996 Catawba lost off-site power for more than a day with one of the two emergency diesel generators unavailable.

That means it was only one generator away from an SBO. NRC estimates that at that time, there was a 0.2% chance that the core of the reactor would have been damaged. In light of the SNL study, it is now known that this corresponded to a nearly one in a thousand chance of a Chernobyl-type accident.

According to Duke Energy's own data, providėd to the NRC in its Individual Plant Examination (IPE) submittals (probabilistic risk assessments done by licensees, without peer review), McGuire has a relatively high probability of experiencing an SBO. Factoring in this probability, NRC obtained a containment failure probability given core damage of 13.9% for McGuire. This result is nearly seven times greater than the value of 2.4% reported by Duke in the McGuire IPE.

Although this value exceeds NRC's guideline that containment failure probability should not exceed 10%, NRC argues that it is "consistent with a general objective" of 10%. However, this result does not take into account "external events" such as earthquakes or tornadoes. A tornado caused a loss of off-site power at the Davis-Besse plant in 1998, and one of the diesel generators became inoperable afterward. Such events are associated with a much higher SBO risk than internal transients.

Therefore, the fraction of core damage scenarios that are also associated

with SBOs would be much higher if external events were included.

For example, according to Duke Energy's own IPE data, the probability of an earthquake causing an SBO at Catawba is over ten chances per million per year. According to a recent NRC proposal, any accident sequence that had a probability of more than one chance per million per year would have to have an early containment failure risk of less than 10%. Catawba, with an early containment risk of 34%, would be in violation of this guideline based on the seismic risk alone.

Station blackout can also occur as a result of sabotage, which hasn't been taken into account in the analysis. For instance, during a recent NRC force-on-force exercise at the Oconee plant, also owned by Duke Energy, mock attackers were able to cut off-site power (this is always assumed to be the case, because the power lines are not protected), defeat the security force and cause core damage. However, the probability of a sabotage-induced SBO cannot be quantified. Therefore, the best line of defense in this case is to ensure that the containment will not fail.

The SNL report concludes that "all [ice condenser] plants, especially McGuire, would benefit from reducing the station blackout frequency or some means of hydrogen control that is effective in station blackouts," noting that the latter course would reduce early containment failure probabilities "by more than an order of magnitude in all plants and especially McGuire.'

However, according to the report, 'previous cost/benefit studies generally do not justify the expense in providing hydrogen control in SBO because ... the SBO probability is a small fraction of the core damage frequency ...'. This assumption has now been called into question.

NRC is in the process of reviewing its regulations on combustible gas control. NRC staff have recently proposed a requirement that ice condensers provide a means for controlling hydrogen in station blackouts unless it can be shown that the probability of a station blackout is acceptably low.

Meanwhile, Duke Energy has learned of the ice condenser report and is already raising doubts about its validity. Duke met with NRC staff on September 28 and vigorously opposed the idea that the installation of new equipment for controlling hydrogen gas accumulation in SBOs might be necessary." [38]

In his response to the NCI report NRC Chair Richard Meserve wrote that:

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[38] http://www.nci.org/e/el-ice-condensers.htm

Even though the vulnerability of ICC plants was judged [by the Sandia report] to be higher for particular severe accident sequences, the overall safety of the plants remains adequate considering the probabilities of these events in the context of the Commission's safety goals. The key finding of the report was that early containment failure in ICC plants is dominated by hydrogen combustion which largely depends on plant-specific probabilities for station blackout. As you stated, ICC plants have igniter systems for hydrogen control and these systems are not operable during station blackout events. The NRC staff shares your thoughts regarding the need to evaluate the functionality of hydrogen igniters during station blackout at ICC plants through the generic safety issue program. The NRC staff informed the Commission of our intention to perform such an evaluation consistent with the policy discussion on backfit considerations in SECY -00-0198, dated September 14, 2000.[39]

3. **Deficiencies in the licensee's operating experience warrant further scrutiny of the ice condenser system aging program(s).**

a. As reported in BREDL's October 25, 2001 Petition to Dismiss:

" On October 8, 1999 the NRC granted the licensee an exemption to 10CFR.54.17.c., thus allowing the licensee to submit a license renewal application earlier than the 20 years before the expiration of the operating license currently in effect.[1]

Part of the basis for the exemption, which was requested on June 22, 1999, was the licensee's assertion of a 'regular and systematic exchanges of information on plant-specific operating experience among all three Duke nuclear stations.' [One of the] two instances... where this statement [was found to be] in error is as follows:

"b. In 1998, the NRC's Allegation Review Board found that 'problems with D.C. Cook Ice Condenser Containment such as configuration and testing, and Ice Basket Bay Doors and Components were known but not reported by D.C. Cook, Watts Bar,

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[39] November 14, 2001 letter from NRC Chairman Richard Meserve to Dr. Edwin S. Lyman . http://www.nci.org/n/nrc111400.htm

[1] Federal Register. Vol 64. No 195. Friday October 8, 1999. 54924-54925. The licensee was already under contract to the Department of Energy to use MOX fuel, but this issue was left unaddressed in the Federal Register notice.

McGuire, and Westinghouse.'[2] Although the ARB classified the concern as 'low' significance, it also illustrated a failure to exchange "information on plant-specific operating experience among all three Duke nuclear stations" in order to correct safety problems; and also implies by omission that McGuire personnel did not share this information with Catawba personnel."

F. Summary

BREDL has presented sufficient information to show a genuine dispute on a material issue of law or fact, including references to specific portions of the application that the petitioner disputes and the supporting reasons for each dispute, and/or identification of each asserted failure of the application to contain information on a relevant matter as required by law, as well as the supporting reasons for the petitioner.s belief that the application fails to contain relevant information required by law. *See* 10

[2] June 22, 1998 Memorandum from Oscar De Miranda, NRC Region II Senior Allegations Coordinator, to Jean Lea, Senior Allegations Coordinator of Office of Nuclear Reactor Regulation. Subject: Tennessee Valley Authority, American Electric Power and Duke Power Ice Condensers—Region II Review of DOL Transcripts. Released by NRC in response to FOIA 2001-0010.

Exhibit 1

Mangano, Joseph J. 2000. *Improvements in local infant health after nuclear power reactor closing.* Environmental Epidemiology and Toxicology (2000) 2, 32-36. 5 Pages.

Environmental Epidemiology and Toxicology (2000) 2, 32–36

www.nature.com/eet

Improvements in local infant health after nuclear power reactor closing

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Between 1987 and 1998, operations ceased at 12 U.S. nuclear power reactors. One of these, Rancho Seco, is located in a densely populated area. After the reactor closed in 1989, significant decreases in mortality (all causes and from congenital anomalies) and cancer incidence were observed for fetuses, infants, and small children. These trends contrast with a worsening of infant health status after the plant opened in 1974. The data suggest that a relationship between nuclear emissions and adverse health effects exists, especially since fetuses and newborns are most sensitive to radiation. Because Rancho Seco released low levels of radionuclides into the local environment, the issue of health effects of prolonged, low-dose radiation exposure is raised. The matter becomes increasingly important as operators of several dozen aging U.S. reactors must soon decide whether to extend their operating licenses. *Environmental Epidemiology and Toxicology* (2000) 2, 32–36.

Keywords: *cancer, infant health, infant mortality, nuclear reactors, radiation.*

Introduction

From 1987 to 1998, utilities permanently closed 12 U.S. nuclear power reactors (U.S. Nuclear Regulatory Commission, 1999). No new orders have been placed since 1978, and thus, many units are aging; 36 of them began operations 25–30 years ago. Utilities running these units must soon decide whether to apply to the U.S. Nuclear Regulatory Commission for a new operating license or to close reactors.

To date, the principal issues associated with reactor closings have been waste management and plant decommissioning. Little consideration is given to health status among local residents. After the Partial Test Ban Treaty ended atmospheric atomic bomb testing in Nevada, and dietary levels of long-lived radioactive chemicals from fallout declined after peaking across the U.S. in 1964 (U.S. Public Health Service, 1968), progress in several infant health indicators accelerated. Long-term declines in fetal and infant mortality abruptly slowed during the atmospheric test era, but fell sharply thereafter (Whyte, 1992). The percentage of American babies born less than 2500 g, which rose 2% for whites and 35% for nonwhites from 1950 to 1966, plunged during the next decade (Mangano, 1998). Cancer incidence ages 0–4 in Connecticut, the only state with an established tumor registry, rose 61% from the early 1940s to the early 1960s before falling 24% in the first five years after the test ban (National Cancer Institute, 1986).

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The fetus and infant are most susceptible to effects of radiation and other toxic chemicals. The developing fetus undergoes rapid cell growth, self-programmed cell death (apoptosis), and cell re-arrangement. The developing infant is similarly susceptible to cellular and metabolic damage. Unrepaired damage becomes magnified with time, increasing the risk of cancer, congenital malformations, underweight births, and fetal/infant deaths (Sherman, 1994).

Five of the 12 closed reactors are in areas at least 70 miles from any other nuclear power plant. In the first two years after closing, infant mortality rates in the closest counties downwind from the reactors fell 15 to 20% at each site (Appendix 1). The average U.S. two-year decline in infant mortality from 1985 to 1996 was 6.4%.

This report assesses potential health impacts of the closing of the Rancho Seco reactor (one of the five cited) on local fetuses and infants. Rancho Seco is located close to a highly populated area (25 miles southeast of Sacramento, California), making detection of significant trends more feasible. It had a large capacity of over 2700 megawatts (thermal), which could potentially affect the local population's health more than a small unit. No other nuclear reactor lies within 200 miles. It has been closed since June 7, 1989 (initial criticality began on September 16, 1974 and commercial operations on April 17, 1975), permitting a long-term analysis of subsequent health patterns to be made.

The opening of Rancho Seco corresponds with an increase of local *in vivo* radioactivity. Estimates of dietary intake of Strontium-90 in urban west (mostly San Francisco) adults were made from 1961 to 1982, based on

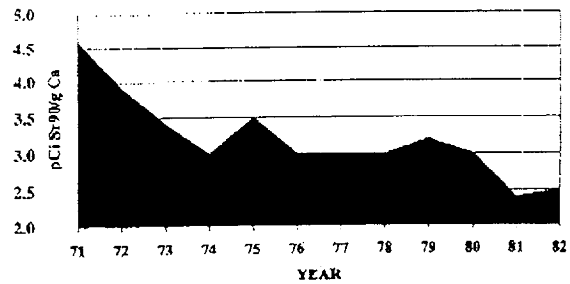

Figure 1. Adult Dietary Intake, Sr-90, Urban West.

post-mortem measurements of human bone. In the early 1970s, Sr-90 concentrations were falling, but from 1974 to 1980, the rate remained at or above 3.0 pCi of Sr-90 per gram of calcium in bone (Figure 1). During the same period, concentrations in urban northeast (mostly New York City) adults declined 22% (Klusek, 1984). It is possible that Sr-90 levels in San Francisco were affected by emissions from Rancho Seco; the reactor lies just 70 miles from the city, while a substantial portion of San Francisco food is grown in the nearest agricultural area, the Sacramento Valley.

Rancho Seco's closing reduced local levels of dietary radioactivity. In 1987, when the reactor was temporarily closed for repairs, an average of 1.91 pCi of Iodine-131 was present in Sacramento's pasteurized milk. After restart, levels rose to 2.67 and 2.54 in 1988 and 1989, but fell to 1.82 in 1990 (National Air and Radiation Environmental Laboratory, 1987–1990).

Methods

The analysis focuses on all-cause mortality for fetuses, infants, and young children; mortality from birth defect ages 0–4; and cancer incidence ages 0–4. County-specific data on California underweight births are unavailable before 1993, and thus not used. The source for mortality information is the National Center for Health Statistics annual compilation *Vital Statistics of the United States* (now available from 1979 to 1996 on the World Wide Web at http://www.cdc.gov, CDC Wonder). Cancer incidence is obtained from the California Cancer Registry. Population figures are decennial U.S. Census counts and estimates for all other years.

Those at greatest potential risk of adverse health effects from radioactive releases live in Amador, El Dorado, Placer, and Sacramento counties. The 1990 population in the region was 1.37 million, of whom three-fourths reside in Sacramento County. Most or all of the population in each county live within 50 miles of Rancho Seco, downwind (north and east) from the reactor (Bair, 1992). Although the Sacramento metropolitan area lies to the northwest, and technically not downwind of the reactor, it is included in the study because of its extreme proximity (10–15 miles). No data are available at the sub-county level.

Trends in infant health when the reactor began operating and when it closed were analyzed. Data for 1972–1973 were compared with 1974–1975, when radioactivity was introduced into the local food and water, and data from 1988 to 1989 (the last reported releases) were contrasted with 1990–1991. The first emissions from Rancho Seco reported to the U.S. Nuclear Regulatory Commission occurred in 1975, at 0.01 Ci of airborne radionuclides with half lives of

Table 1. Changes in health status before and after Rancho Seco closing, Amador, El Dorado, Placer, Sacramento Counties, 1988–1989 vs. 1990–1991.

	Four CA counties				U.S.			
	Number		No./1000 births		No./1000 births		Odds ratio	
Indicator	1988–1989	1990–1991	1988–1989	1990–1991	1988–1989	1990–1991	Local	U.S.
Fetal deaths, gestation > 20 weeks	271	288	6.1	5.8	7.5	7.4	0.957	0.987
Deaths < 1 year	424	397	9.5	8.0	9.9	9.1	0.843 ($p<0.09$)	0.919
Deaths < 1 year, congenital anomalies	90	79	2.0	1.6	2.0	1.9	0.791	0.942
[a]Death ages 1–4, excluding accidents, homicide, suicide	51	45	31.1	24.7	28.2	26.8	0.794	0.949
[a]Death ages 1–4, congenital anomalies	14	11	8.6	6.0	6.3	5.9	0.707	0.930
[a]Cancer cases, ages 0–4	39	27	23.7	14.9	19.8	21.0	0.628 ($p<0.07$)	1.062[b]

[a]Rate expressed as cases/deaths per 100,000 population.
[b]Change in 11 U.S. states and cities.

Table 2. Changes in health status before and after Rancho Seco closing, Amador, El Dorado, Placer, Sacramento counties, 1988–1989 vs. 1990–1996.

Indicator	Number 1990–1996	Odds ratio Local	U.S.	Significance
Fetal deaths, gestation >20 weeks	No data available after 1992			
Deaths <1 year	1214	0.761	0.840	0.02
Deaths <1 year, congenital anomalies	267	0.799	0.876	0.23
[a]Cancer cases, ages 0–4	153	0.746	1.066[b]	0.0003
[a]Deaths 1–4, excluding accidents, homicide, suicide	146	0.689	0.836	0.05
[a]Deaths 1–4, congenital anomalies	27	0.460	0.798	0.06

[a]Rate expressed as cases/deaths per 100,000 population.
[b]Change in 11 U.S. states and cities from 1988–1989 to 1990–1993.

over 8 days including barium-140, cesium-137, iodine-131, strontium-89, and strontium-90. The last emissions were reported in 1989, at a level of 0.0003 Ci (Brookhaven National Laboratory, 1970–1992). The post-closure period is also extended to 1990–1996 to assess longer-term trends. No data are yet available after 1996.

Death rates for infants under 1 year are expressed as deaths per 1000 births, while death and cancer incidence rate ages 1–4 are per 100,000 persons. Odds ratios are used to express rate changes in the periods before and after reactor startup/closing. A ratio of 0.900 represents a 10% decline in rate.

Results

Available fetal/infant health measures show a lack of progress from 1972–1973 to 1974–1975 in the four county region. Locally, the fetal death rate (gestation over 20 weeks) fell 1.8% (O.R.=0.982) versus a 7.5% drop in the U.S. (O.R.=0.925). The infant death rate rose 1.9% (O.R.=1.019), while the national rate declined by 9.4% (O.R.=0.906). The number of deaths from congenital anomalies increased 18.6% (O.R.=1.186) while falling 6.9% nationally (O.R.=0.931); no age-specific data by cause at the county level exist, but the majority of congenital anomaly deaths occur in infancy.

By the late 1980s, more fetal/infant health data had become available. The California Cancer Registry initiated a comprehensive database of all cancers diagnosed in the state beginning in 1988. Age-specific congenital anomaly death records became available from the National Center for Health Statistics beginning in 1979. Table 1 shows trends in these radiation-sensitive disorders plus all-cause death rates from 1988–1989 to 1990–1991, before and after the closing of Rancho Seco.

Immediately after the reactor closed, local rates of deaths from all causes, deaths from congenital anomalies, and cancer cases declined faster than the U.S. average. The fall in mortality was especially sharp for congenital anomaly deaths ages 0–1 and 1–4 (O.R. 0.791 and 0.707). Cancer cases age 0–4 also experienced a rapid decline (O.R. 0.628) at a time when the national rate was rising in the 11 U.S. states and cities with available data (Mangano, 1999). When the post-closing period was extended to 1990–1996, local decreases continued to surpass national trends (Table 2). Declines for all but one measure, are statistically significant.

Discussion

Fetal and infant health near Rancho Seco lagged following reactor startup, and improved significantly for at least 7 years after closing. In the Rancho Seco area, fetuses were exposed to radioactive emissions consumed in the maternal diet from 1974 to 1989. Radioisotopes with a short physical half-life disappear soon after emissions cease, while levels of longer-lived radioisotopes diminish gradually.

Because rates declined for children aged 1–4 in the first 2 years after closure, it appears that reducing exposures after birth to those exposed *in utero* may arrest the development of cancer or delay the onset of death almost immediately.

Like other U.S. nuclear power reactors, Rancho Seco emitted low levels of radiation, meaning only small doses were received by the local population. Over its 15-year operating life, 0.1397 Ci of airborne radioactivity with half-lives over 8 days were reported. This figure is about 1/100th of the 14.2 Ci escaping from Three Mile Island during its partial meltdown in late March 1979 (Brookhaven National Laboratory, 1970–1992).

Harmful effects of low-dose radiation exposure to the very young were first demonstrated in the 1950s, when *in utero* pelvic X-rays were associated with an elevated risk of the child developing cancer before age 10 (Stewart et al., 1958). Subsequently, childhood cancer has been positively correlated with other low-dose exposures, including background gamma radiation (Knox et al., 1988; Hatch and Susser, 1990) and emissions from various European reactors (Heasman et al., 1986; Roman et al., 1989;

Gardner et al., 1990; Viel and Richardson, 1990; Goldsmith, 1992; Michaelis et al., 1992; Schmitz-Feuerhake et al., 1997). In the U.S., elevated childhood cancer rates (Johnson, 1981; Goldsmith, 1989; Jablon et al., 1991) and unexpectedly high fetal deaths, infant deaths, and underweight births (DeGroot, 1972; Sternglass, 1972) have been documented near American reactors. Rises in U.S. infant mortality, leukemia, and hypothyroidism after Chernobyl, which added only slightly to the radioactivity in milk and water, have been reported (Gould and Sternglass, 1989; Mangano, 1996, 1997). Each of these reports addresses the presence or addition of environmental radioactivity, suggesting that a negative correlation between adverse health effects and removal of reactor emissions might exist.

There are several limitations to this analysis. Information on uptake of radioactivity is limited; measurements of Sr-90 in vertebrae ended in 1982, while monthly milk concentrations of Barium-140, Cesium-137, and Iodine-131 reported in 60 U.S. cities ceased in 1990. The study mostly covers death rates; aside from cancer, no local disease incidence registries exist. No examination is made of effects to the adolescent and adult populations. Finally, radiation exposure is just one of many potential factors affecting infant health, and it is very difficult exactly to determine what proportion of disease rate declines is due to Rancho Seco's closure.

Future assessments should address not just the Rancho Seco area's infants and children, but persons of all ages living near closed plants. Studies should move beyond the scope of statistical analysis, and measure *in vivo* levels of radioactivity, similar to the study of Sr-90 in St. Louis baby teeth in the 1950s and 1960s (Reiss, 1961; Mangano et al., 2000). With many reactors aging, a thorough knowledge of the relationship between long-term low-dose exposure and health effects to humans is a critical factor in the decision whether or not to continue operations (Nussbaum and Kohnlein, 1994).

Appendix 1

Change in Infant Mortality, Two Years Before and After Reactor Closing, Downwind Counties Within 50 Miles of Reactor, Areas with No Other Power Reactors Within 70 Miles

Reactor (Closing Date) Counties	Infant Deaths Before	Infant Deaths After	Per 1000 Births Before	Per 1000 Births After	% Change
LaCrosse (1987) -LaCrosse WI -Vernon WI	36	30	10.27	8.69	−15.3
Rancho Seco (1989) -Amador CA -El Dorado CA -Placer CA -Sacramento CA	418	390	9.39	7.89	−16.0
Fort St. Vrain (1989) -Larimer CO -Weld CO	83	72	8.53	7.22	−15.9
Trojan (1992) -Columbia OR -Multnomah OR -Clark WA -Cowlitz WA -Wakhiakum WA	253	204	8.34	6.85	−18.0
Millstone/Haddam Neck (1995) -Middlesex CT -New London CT -Tolland CT -Windham CT -Kent RI -Washington RI	166	130	7.46	6.16	−17.4
U.S. Average, 1985-96					−6.4

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Exhibit 2

Gamache, Gerald L, Dennis L. Reeves, Daniel M. Levinson, and Peter I. Bidiouk. 2001. *Neurocognitive and Physical Abilities Assessments Twelve Years After the Cherynobyl Nuclear Accident.* Prepared for the Defense Threat Reduction Agency (DTRA) U.S. Department of Defense. DTRA-TR-00-14. 120 Pages.

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Technical Report

Neurocognitive & Physical Abilities Assessments Twelve Years After the Chernobyl Nuclear Accident

Approved for public release; distribution is unlimited.

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Defense Threat Reduction Agency
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13. ABSTRACT *(Maximum 200 words)* In an effort to assess the effects of exposure to ionizing radiation on neuropsychological and physical abilities, a longitudinal study in and near Chernobyl, Ukraine was conducted. In this report are findings from 1995 to 1998. Participants were volunteers who resided in Ukraine during and since the Chernobyl Nuclear Power Plant accident. A translated subset of the Automated Neuropsychological Assessment Metrics battery and the Gamache Physical Abilities Battery were administered to a control and three experimental groups. Controls were healthy volunteers who resided well outside of the exposed area. Eliminators were decontamination and reconstruction workers with known levels of exposure. Forestry and Agricultural workers resided and worked in contaminated areas. Analyses of 1995 – 1998 4-year averaged results indicated the Eliminators were significantly impaired on all measures of neurocognitive			
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and physical performance as compared to Controls. Forestry and Agricultural workers were impaired on subsets of the neurocognitive and physical batteries. Significant correlations between levels of radiation dosage and 4-year averaged physical and cognitive performance were observed on 21 of 24 tasks for the combined exposure groups. The results appear to reflect the existence of clinically meaningful neurotoxic effects of both acute and chronic exposure to radionuclides.

PREFACE

This document represents the Final Report of a four year effort sponsored by the Defense Threat Reduction Agency (DTRA). This report provides the Tables and Figures to substantiate the effects of low-dosage radiation (less than 70 rads) on a Ukrainian population exposed as a result of the Chernobyl disaster.

The success of this study was dependent on the active participation of a group of subject matter experts from military and civilian services on an international basis. Our first line acknowledgment and sincere appreciation is extended to our sponsor, the United States Defense Threat Reduction Agency (DTRA). Further, special thanks goes to Robert A. Kehlet, our Program Manager at DTRA. He has been our champion in this project, and successes to date are due to his dedicated scientific and program guidance.

Development of the TWB/ANAM, which has served as the neuropsychological test instrument in this project, was sponsored by the U.S. Army Office of Military Performance Assessment Technology, Walter Reed Army Institute of Research, Washington, DC, Dr. F.W. Hegge, Program Director. The TWB/ANAM system was constructed at the Naval Computer & Telecommunications Station, NAS, Pensacola, FL, K. P. Winter, Principal Investigator. Authors of the ANAMUKR Battery were D. Reeves, G. Gamache, A. Chervinsky, & P. Bidiouk. Finally, the authors would like to express a special note of appreciation for the exceptional volunteer technical assistance provided by Dr. J. Wood, Krug Life Sciences during the English to Russian/Ukrainian portion of this project. Her knowledge and experience with the NASA-MIR projects proved invaluable in helping us to not "re-invent" the wheel and launch our project "on-schedule."

On-site Supervisors in the Ukraine were: Damian V. Kolisnyk, who supervised all aspects of testing the control group, Nikolay N. Kaletnik, who supervised all aspects of testing the forestry workers, and Victor G. Bondarenko, who supervised all aspects of testing the eliminators. Dr. Peter I. Bidiouk was the on-site project scientist and over-site supervisor for all aspects of the selection of test sites and the selection of participants, as well as being the on-site project administrator in Ukraine (see Appendix A).

Finally, the authors would like to express sincere appreciation to Dr. A. J. Glasner, National Cognitive Recovery Foundation Editorial Board Member, who has been instrumental in production of this report and helping us remain "on-track" and in adherence with NCRF/APA guidelines.

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ⟶	**BY** ⟶	**TO GET**
TO GET ⟵	**BY** ⟵	**DIVIDE**

angstrom	1.000 000 X E -10	meters
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 X E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 X E +1	*giga becquerel (GBq)
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_k = (t°f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (u.s. liquid)	3.785 412 X E -3	meter^3 (m^3)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (j/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/ m^2 (N-s/m^2)
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N˙m)
pound-force/inch	1.751 268 X E +2	newton-meter (N/m)
pound-force/foot^2	4.788 026 X E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 X E -2	kilogram-meter^2 (kg˙ m^2)
pound-mass/foot^3	1.601 846 X E +1	kilogram-meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 X E -2	**Gray (Gy)
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	seconds (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm Hg, O° C)	1.333 22 X E -1	kilo pascal (kPa)

- The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.

**The Gray (Gy) is the SI unit of absorbed radiation.

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SECTION 1
INTRODUCTION

The nuclear reactor accident at Chernobyl in 1986 resulted in geoecophysical damage and polluted farmlands and forests with radioactive contamination in im
mediate and outlying areas. It has been estimated that 72% of the land mass of Ukraine is contaminated, and will be so for thousands of years (Yakovlev, 1992). By 1988, the Ukrainian registry contained names of 347,619 civilians who had experienced medical symptoms that are frequently associated with exposure to the ionizing radiation fallout. In addition, 36,000 military personnel (Yakovlev, 1992) were listed as adversely affected. By 1992, over 1.5 million individuals were on government registries as having suffered medical problems associated with radiation exposures. This group included 350,225 children and 180,144 persons assigned to "clean-up" duties at or very near the accident site (Awramenko, 1992). By 1993, about 7,000 people had died from apparent radiation-related illnesses, including heart, vascular, respiratory, and digestive diseases. One area of investigation that has been neglected during the aftermath of the Chernobyl accident has been the possible long term and subtle effects on neuropsychological functions.

According to Chernousenko (1991) and Gittus et al. (1988), construction started on the Chernobyl Nuclear Power Plant (CNPP) in March, 1970. Plans called for construction of six High Power Channel Reactors, each having the capability to generate 1,000 megawatts of electricity. These are single-loop reactors, which means that steam travels directly to the turbine for electric generation. On September 28, 1977, the first of four reactors for CNPP became operational. Engineers working at the site warned of substantial problems because the reactor was unstable and emitting small doses of radioactivity. Despite these problems, more reactors were built, all operational until Saturday, April 26, 1986, when at 1:23 AM the fourth reactor exploded. The blast ripped off the roof and radioactive waste in the form of plutonium, cesium, and uranium dioxide were released (see Figure B-1 in Appendix B).

At the reactor site, a 30-kilometer exclusion zone was established by the government to keep out non-scientific personnel. Cleanup and containment crews were dispatched to the scene where approximately 660,000 volunteers and soldiers were employed. Only the Russian radiation monitors were outfitted for the task at hand (Figure B-2). The rest were "eliminators" composed of military units (infantry, helicopter crews, and engineer units), Ukrainian police, tractor and truck drivers from all Ukrainian provinces, medical doctors and nurses, scientists and engineers from Ukraine, Belarus, and Russia, and farm laborers (men and women) from Ukraine and Russia. The Ukrainian volunteers were approximately 396,515, while those living in Belarus and Russia comprised approximately 264,343. These cleanup crews were dressed only in surgical masks and lead aprons (Chernousenko, 1991). In neighboring Pripyat the population of 55,000 was not evacuated until 36 hours post-accident. Meanwhile in Kiev, government officials detected large doses of radiation; however, they chose not to cancel a planned May Day parade.

Several years later, the accident continued to bring suffering to millions of people in the Ukraine, Belarus, and Russia. According to Baranov and Guskova (1988), and Laupa and Anno (1989), thirty-one workers at Chernobyl Nuclear Power Plant died a little over three months post-accident as a result of acute radiation sickness.

Baryahtar (1991) reported that as many as 7,000 have died since then of radiation-related illnesses, and The International Chernobyl Project claimed that the scientific community lacked research and information on the medical consequences of radioactive pollution. Read (1993) stated that the number of fatalities ranged from thirty-one to "a projection that Chernobyl will ultimately claim more victims than did World War II."

According to the newspaper Vestnik Chernobylia, Ukraine produces 54.4 million kilowatts-year of energy annually. Over 62% is generated from coal or oil burning plants, 8.3% from hydroelectric plants, 23.5% from other nuclear power stations, and 5.5% from the two operating reactors at the Chernobyl Nuclear Power Plant. In the winter of 1992-1993, nuclear power plants accounted for 40% of all electric power generated. In 1990, 5.8% of this power was generated by Chernobyl; in 1991 the rate dropped to 5.2% while in 1992 the rate was only 2.2%.

Two reactors are still operational at Chernobyl (Figure B-8). The third reactor was destroyed in a fire in October, 1991. Each reactor is programmed for 30 years of service; however, the two remaining reactors were scheduled to be deactivated in 1993. Decommissioning will cause substantial problems because the four reactors have generated over 244 million kilowatts-year of energy, including 94 million kilowatts-year since the accident. The two remaining reactors have the capability of generating 10.3 million kilowatts-year of electrical energy at a cost of $515 million dollars. Utilizing them would save 2.6 million tons of oil or 6.1 million tons of coal, purchases the Ukrainians cannot afford. In October, 1993, the law which would have closed Chernobyl by the end of 1993 was repealed.

For the year 1989, the absorbed dose for people at Chernobyl was 1.3 rads compared with a lifetime dose of 35 rads. In 1992, the absorbed dose was only .97 rads. The amounts released into the atmosphere by the cracking sarcophagus comprise only 20% of the rate of the fully functional reactor.

Decommissioning will involve four steps. First, the reactors are shutdown with a one-year cooling period. In step two, the nuclear fuel is removed and kept in water for one to two years before placing it in special storage. In stage three, Chernobyl will be temporary closed for a period of 20 to 30 years to allow any radionuclides present in the facility to decay. Finally, in stage four, Chernobyl will be dismantled.

When Chernobyl was fully operational, a total of 50,000 persons worked at four reactors. By 1987-1988, 90% of these workers had been replaced. Of the replaced workers, more than 90% were under the age of 45 and 60% graduated from a university or technical colleges. Today, the 25,000 present staff lived about 50 kilometers from Chernobyl in the town of Slavutych, which was constructed in 1986 after the town of Prypiat was evacuated.

Debate over the future of Chernobyl is still going on in the Ukrainian Supreme Soviet. On one side of the debate are those who believe the economy of Ukraine will not improve by decommissioning. They point out the replacement cost of alternative methods of generating electricity. They also point out the Dnieper basin has seven other reactors with the same design as Chernobyl, and another similar reactor will soon be operational near Kursk. They argue that Chernobyl has a highly trained staff which will go elsewhere if the reactors are decommissioned, and each year savings from nuclear power can be turned to clean-up efforts and treating those still suffering from the accident.

Finally, they argue that other third-world governments are not decommissioning Russian-made RBMK reactors; in fact, Russia is planning to double energy production by nuclear power by the year 2010, although they will not rely on the RBMK reactor.

According to Yakovlev (1991), the Chernobyl incident resulted in waste emission of approximately 50-80 million Curies (Ci), including over a million Ci of Cs^{137}, 200,000 Ci of Sr^{90} and between 3,500 and 5,500 Ci of $Pu^{239/240}$ into the environment.

His research states that as of January 1, 1992, forty three thousand square kilometers, or 15% of the Ukraine, was contaminated by Cs^{137}, with doses greater than one curie per square kilometer. Over 72% of Ukraine is contaminated above background radiation. This area has 3,200 towns and villages and a population, excluding Kiev, of over 4,000,000 people. Migratory birds and animals carry radiation-related diseases along their routes, increasing the contaminated area. Table 1-1 (Sobodovych et al, 1992) shows contamination from Chernobyl as compared with that resulting from nuclear weapons tests. While Chernobyl nuclear contamination is low compared with Russian nuclear weapons tests, the scientific community cannot afford to forget the fact that Chernobyl is adjacent to a heavily populated area.

Table 1-1. Comparison of radionuclide content released into the environment as a result of nuclear weapons tests with levels resulting from the Chernobyl accident.

Type of radio-nuclide	Half-life in years	Nuclear weapons test (million Ci)	Total in reactor (million Ci)	Chernobyl outburst %	Chernobyl outburst (million Ci)	% of NWT
Sr^{90}	28.60	57.5	6.00	6.0	0.30	0.50
Cs^{137}	30.17	87.0	7.02	30.0	2.10	2.40
Pu^{238}	87.74	0.0055	0.0254	9.0	0.00076	13.80
Pu^{239}	24118.00	0.96	0.0256	9.0	0.00077	0.20
Pu^{240}	6570.00	0.50	0.040	9.0	0.0012	0.20
Pu^{241}	1435.00	23.00	4.97	9.0	0.15	0.70
Pu^{242}	$.763x10^5$	0.00045	0.000056	9.0	0.000002	0.40

It should be noted that 50-80 *million* curies of radiation were released into the environment from the Chernobyl accident, as compared to only 14-20 from the Three Mile Island incident.

During the accident, reactor cooling water was flushed into the Prypiat River, a tributary of the Dnieper, rather than allowing more radioactive steam to escape into the atmosphere (Chernousenko, 1991). The result of this action, and the break in the sewage system that serviced the Chernobyl cleanup effort, are the principle causes of radionuclide pollution in the Dnieper and Prypiat rivers, as well as their water reservoirs which serve to irrigate the region. Thus the contamination is spread. At present, the vertical migration of radionuclides approaches a depth of one meter from the surface.

According to Professor V. Kopeikin (1993), water near the burial place of Chernobyl debris is about 4 meters underground. Ten wells with filters installed were constructed on-site to monitor ground water contamination. These wells are monitored daily and were placed every four meters, with depths ranging from 8-9 meters.

The damaged reactor is covered by a sarcophagus composed of 220,000 m^3 of concrete and 15,000 m^3 of steel, around which there are 5 to 6 meters of "clean topsoil" (Yakovlev, 1991).
However, the sarcophagus has approximately 700 square meters of heat cracks caused by the damaged reactor core underground. The cracks cause venting of radioactive materials from fragments of the reactor core and the graphite bed underneath it. About 75% of the residual nuclear fuel is composed of clinker (135 tons) and nuclear dust (10 tons). The maximum temperature at the surface is 60 degrees centigrade, while the temperature underground approaches 200 degrees centigrade.
On the surface radioactive contamination is about 3,000 roentgen per hour. In 1990-1991 the outburst from radioactive dust was 1,000 times less than that of a working reactor. However, with time and clinker decomposition, the amount of nuclear dust will increase. On May 30-31, 1990, Chernobyl was struck by an earthquake measuring 4.0 on the Richter scale. No damage to the sarcophagus was reported. In 1992 the Ukrainian government opened bidding on a replacement sarcophagus. In June, 1993, the lowest bidder, a French company, began studying the problem. During 1987-1990, 270,000 rubles were spent to increase safety of all reactors in the Ukraine.

According to Woytsehowich (1991), as shown in Table 1-2, between 1986-1990 the amount of Cs^{137} in the Kiev water reservoir increased more than 17 times. In the Kremenchug reservoir, approximately 170 miles south of Kiev, the pollution has doubled; this signifies a spreading of radionuclides along the Dnieper basin.

Table 1-2. Volume of Cs^{137} in the Dnieper reservoirs, measured in curies.

Reservoir	1986	1987	1988	1989	1990
Kiev	413	850	--	1000	7200
Kanev	60	--	--	570	2200
Kremenchug	150-200	--	218	294	294

The maximum values of specific activity of radionuclides as well as heavy metals are in riverbeds and shallow bays, while the minimum values are in the floodlands and irrigated fields. From CNPP, along the Prypiat and Dnieper rivers, down to Kiev Reservoir, three contamination zones have been established (Woytsehowich, 1991) for those areas affected by Cs^{137}. The Migration Zone lies along the Prypiat river between CNPP and its entrance into the Dnieper. The Accumulation Zone is from the mouth to 15 kilometers upstream from the reservoir dam. The Wash Away Zone is from the point 15 kilometers from the dam to the dam itself.

Table 1-3 (Sobodovych et al., 1992) shows soil contamination in Kiev and its suburbs to be .015 to 5.31 Ci/Km^2 for Cs^{137}, .02 to .80 Ci/km^2 for Ce^{144}, and .03 to 1.57 Ci/km^2 for Ru^{106}. Not shown in Table 1-3 is the contamination by Sr^{90}, which is 50-750 Ci/Km^2. The concentration of plutonium was reported by two sources. Source 1 (Ukrainian) shows the level of contamination to be 5 to 10 Ci/km^2, while Source 2 (Russian) shows the level of contamination to be much lower--0.1 to 2.7 Ci/km^2. The authors were given no explanation for these disparities.

Table 1 –3. Distribution of radionuclides in Kiev and suburbs.

Radionuclide	Activity (Ci/kg)	Density of contamination (Ci/km^2)
Cs^{137}	$2.6 \times 10^{-10}/7.94 \times 10^{-8}$	0.015-5.31
Ce^{144}	$3.06 \times 10^{-10}/1.12 \times 10^{-8}$	0.02-0.80
Ru^{106}	$4.31 \times 10^{-10}/2.19 \times 10^{-8}$	0.03-1.57

Note:
(1) Maximum Contamination Levels in Kiev
1880 mCi/km^2 (Kudry, Pechersk)
4524 mCi/km^2 (Montazbnikov, Sovley)
1182 mCi/km^2 (Davydova, Rusanovka)
1367 mCi/km^2 (Kybalchiucha, Voskresenka)
1105 mCi/km^2 (Kosmomantov, Otradny)
(2) Pu Contamination:
Source 1: 5 - 10 Ci/km^2
Source 2: 0.1 - 2.7 Ci/km^2

The city of Kiev comprises 340 km^2; however, only 7% is contaminated, mostly with Cs^{137}. As shown in Tables 1-4 and 1-5 (Sobodovych et al., 1992), in the largest area in the Kiev region which includes the city plus surrounding countryside, fifty percent of the total landmass has received greater than 40 Ci/km^2 of contaminated radiation. This exceeds the recognized standard for lifetime exposure rate of 40 Ci/km^2; however, the city itself is quite habitable.

Dr. Kaletnik, Head of the Scientific and Technical Office for the Ministry of Forest, was questioned why the Kiev region, rather than the city itself, was so highly contaminated. He explained that this phenomenon was due to excessive forest fires in the area, and that rising smoke and soot which blankets an area after rainfall would increase already high levels of contamination.

Table 1-4. Contamination by Cs^{137}.

Concentration Intervals (Ci/Km^2)	0.5-1.0	1.0-5.0	5.0-15.0	15.0-40.0	< 40.0	Sum
Region	**Contamination of Cs^{137} measured in square kilometers**					
Polissya	1837.5	2000.0	187.5	-	-	4025.0
Korosten'	2162.5	92.5	2625.0	1125.0	-	6005.0
Upper-Prypiat	950.0	1900.0	187.5	-	-	3037.5
Kiev	5100.0	3575.0	4750.0	4500.0	18000.0	35925.0
Carpathian	62.5	-	-	-	-	62.5
Chernigov	687.5	75.0	-	-	-	762.5
Ternopol	2125.0	1000.0	-	-	-	3125.0
Podilsk	2500.0	4075.0	975.0	-	-	6975.0
Lviv	37.5	-	-	-	-	37.5
Mukachev	150.0	75.0	-	-	-	225.0
Pridneprov	437.5	325.0	-	-	-	762.5
Avratynsk	2412.5	3175.0	150.0	-	-	5737.5
Samarskij	337.5	37.5	-	-	-	375.0
Donetsk	875.0	350.0	-	-	-	1225.0
South Bogs	75.0	-	-	-	-	75.0
Total	**19750.0**	**16680.0**	**8275.0**	**5625.0**	**18000.0**	**68330.0**

Table 1-5. Contamination by Sr^{90}.

Concentration Intervals Ci/Km^2)	0.05-.50	0.50-1.0	1.0-3.0	<3.0	Sum
Region	**Contamination of Sr^{90} Measured in Square Kilometers**				
Polissya	125.0	-	-	-	125.0
Korosten'	312.5	312.5	312.5	-	937.5
Upper-Prypiat	187.5	156.3	-	-	943.8
Kiev	687.5	625.0	2500.0	1875.0	5687.5
Carpathian	15.6	-	-	-	15.6
Chernigov	437.6	-	312.5	-	750.1
Ternopol	31.3	-	-	-	31.3
Podilsk	812.5	156.3	-	-	968.8
Lviv	-	-	-	-	-
Mukachev	-	-	-	-	-
Pridneprov	281.3	156.3	-	-	437.6
Avratynsk	812.5	625.0	-	-	1437.5
Samarskij	-	-	-	-	-
Donetsk	-	-	-	-	-
South Bogs	15.6	-	-	-	15.6
Total	**3718.9**	**2031.4**	**3125.0**	**1875.0**	**10750.3**

Measurements for Table 1-6 (Sobodovych et al., 1992) were taken in May, 1986, a few weeks after the Chernobyl disaster; these show radionuclides in the suburbs of Kiev, approximately 15 to 20 kilometers from Kiev's center.

Table 1-6. Radionuclide activity in suburbs of Kiev: May, 1986.

Type of test	Location: S-SE Koncha-Zaspa (Ci/km^2)	Location: N-NE Puscha-Wodyca (Ci/km^2)
Ground (0-3cm deep)	3.08×10^{-8}	0.51×10^{-7}
Ground (3-10cm deep)	1.22×10^{-3}	0.69×10^{-7}
Pine trees	1.00×10^{-3}	4.54×10^{-6}
Pine tree bark	2.63×10^{-7}	0.71×10^{-6}
Carpet	1.00×10^{-3}	0.95×10^{-5}
Grass	4.97×10^{-6}	0.93×10^{-5}

Note: These suburbs are located 15-20 km from Kiev.

Finally, tritium, a radioactive isotope of hydrogen, was present at Chernobyl (Woytsenhowich, 1991). Tritium emits negative beta particles of 19,000 electron volts of energy and has a half-life of 12.5 years. Table 1-7 (Sobodovych et al., 1992) shows the testing of water contaminated by tritium. Since tritium naturally occurs in water, probably the action of cosmic rays on atmospheric hydrogen, one would need prior testing to determine if these measurements were significant. If they were significant, the dates of these measurements might indicate serious problems.

Table 1-7. Contamination of water by tritium.

Type of Water	Date of test	Number of test	Concentration (Bk/Liter) Range	Median
1. Atmospheric (Snow, Water)	Jan 92-Feb 92	51	2.7 to 6.4	3.5
2. Surface Water	Nov 91-Jan 92	124	2.7 to 11.8	4.8
3. Ground Water	Nov 91-Jan 92	101	2.7 to 12.7	5.1
4. Underground Water	Sep 91-Jan 92	68	2.2 to 5.2	2.2

Within weeks following the Chernobyl disaster, measurements to assess damage to forests surrounding the area were taken. Ultimately, about 500 hectars of forests were destroyed as a result of the accident. The government established a 30-kilometer fenced zone around the reactor with military patrols, whose purpose was to prevent unauthorized access. Even outside this zone, the density of contamination was 10 to 80 Ci/km^2. At least 28,000 km^2 of forest were contaminated.

The first reported measurement of gamma radiation occurred on May 16, 1986, 20 days post-accident (Sobodovych, 1992). Two devices were used for measurements. The first device, the Russian Army DP-5B, was available to units working in nuclear contaminated battlefields where it was used for rough estimates of nuclear contamination. The second device, SRP-6801, yielded more precise measurements and was carried by engineers who surveyed the site. Table 1-8 shows the results for measurements inside the 30-kilometer zone and adjacent forest areas. Approximately 100 hectare grids were laid out on maps by the Ministry of Forest. A sampling technique was then utilized. The number in parentheses following the forest name in the first column denotes the grid area.

Table 1-8. Measurement of gamma radiation for 30-km zone and adjacent areas, May 16, 1986.

Location of the measurement	DP-58 (millirads/hr) Army device	SRP-6801 (millirads/hr) (more precise)
1. Polissia Forest (18)		
Meadows	0.14	0.20
Free in air	0.10	0.25
Grass	0.12	0.25
Carpet	0.20	Not Measured
2. Radynskoye forest (12)		
Forest edge	0.13	0.25
Meadows	0.20	0.41
Trees	0.26	0.44
Carpet	0.22	0.42
Village of Cheremoshe	0.20	0.38
3. Radynskoye forest		
Edge of pine trees	0.75	1.25
Young mixed trees	0.75	1.50
Free in air	0.75	1.40
Crown of trees	0.75	1.45
Grass	0.80	1.50
Moss	1.50	1.50
Oat field	0.45	1.25
Ground	0.70	0.70

Note: numbers in parentheses show grid number denoting location of sampling squares.

Table 1-9 (Sobodovych, 1992) shows gamma radiation in forests south of the reactor. Measurements were also made in May, 1986. These forests contain coniferous trees, which are especially vulnerable to radiation. This table is useful because the distance from the reactor is measured, as well as the growth of pine trees in a particular forest.

Table 1-9. Gamma radiation in forest south of Chernobyl at various distances: May,1986; Device: DP-58 (millirads/hr).

Location	Free in air	Carpet
1. Dymer forest (100 km*) Pine trees-50 years old	0.6	1.0
2. Ivankov forest (80 km*) Pine trees-80 years old Pine trees-50 years old Pine trees-18 years old	 0.7 1.5 1.3	 0.7 2.8 3.2
3. Chernobyl forest (20 km*) Pine trees-30 years old	3.5	10.0
4. Novoshepelychi forest (10 km*) Pine trees-30 years old	10.0	30.0

Note: * denotes kilometers from reactor to center of forest.

Table 1-10 is extremely interesting, since it shows the result of forest damage within the 30- kilometer zone. It was constructed based on conversations with Mr. Kaletnik. This table was cited in the Pacific-Sierra Research Corporation's analysis of Landsat imagery (McClellan, G.E. et al., 1994). The distance from the reactor site is approximately one kilometer, and as Table 10 reflects, 100% of the trees located 350 meters from the edge of the forest were recovered and sent to mills to be used as lumber. The rest of the trees were bulldozed into large pits and covered with topsoil. This action has increased ground contamination, and the Ukrainians are presently reviewing options to deal with this situation.

Table 1-10. Result of forest damage by radiation within the 30-kilometer zone.

Distance from the edge of the forest	Calculated absorbed Dose—Rad x 10^3	% of tree crown damage	Degree of harm	% of recovered trees
Edge of forest	10	100	Completely dry Wood	0
35 meters	6.5	50	Very strong	25
90 meters	4.9	20-30	Medium	50
350 meters	0.5	Up to 10	Small	100

In 1986, the crowns of trees contained about 50% of the radionuclides (Yakovlev, 1992). By 1988, 95% of the radionuclides were in humus or carpet. Today, most radionuclide content of the foliage has migrated through the root system.

Beginning in the summer of 1988 measurements were made of radioactive particles within the 30-kilometer zone in an area called the "Brown Forest", so named because the leaves and vegetation were discolored by radiation. Table 1-11 (Sobodovych, 1992) shows the results of these measurements, with the percentages of each isotope listed. The table also displays the particle properties as either irregular shaped flakes or round balls with varying composition of beryllium, cuprum, lead, silicon, tantalum, and iron. High concentrations of cerium, cesium, and ruthenium are shown.

Table 1-11. Radioactive particles from the brown forest.

Date of Test	Form, size (mcm), and properties of particles	Basis of particle	Element (percentages) Ce^{144}	Cs^{134}	Cs^{137}	Ru^{106}	Co^{60}
Jun 1988	Black, hard, magnetic balls, 46.7 mcm	Oxides of Fe	2.0	-	2.0	94.0	2.0
Aug 1988	Irregular, 1.2-6.5 mcm and Balls, 4.1-5 mcm, dark br	Be, Pb, Cu	54.2	5.4	15.5	24.9	-
Jan 1989	Irregular, 1.6-88.0 mcm, dark br, nonmagnetic	Fe, Si, Pb	50.0	4.5	22.3	29.0	-
Jan 1989	Irregular, fragile, black, Nnnmagnetic, 2.0-20 mcm, Balls, 1.0-4.0 mcm	Fe, Si	4.0	8.9	92.6	24.5	-
Jan 1989	Irregular, 1.2-6.4 mcm, dense, black, with balls, 0.6-2.4 mcm	Si, Ta	88.2	0.8	3.8	7.2	-

Table 1-12 (Sobodovych, 1992) displays a list of forests contaminated by Cs^{137} and the levels of contamination. These measurements were made in 1990 and 1991. Figures for 1992 were not available.

Table 1-13 (Woytsehowich, 1991) shows measurements taken from Kiev in 1991 in which foliage samples were collected, burned, and analyzed for Sr^{90} and Pu. These measurements were taken in three parks in Kiev proper. Leningradskaya Square is in the center of downtown Kiev, and the hydropark lies along the Dneiper River to the east of downtown.

Finally, Tables 1-14 and 1-15 (Baryahtar & Bobyleva, 1991) reflect the Ukrainians' concern with individuals growing, harvesting, and consuming food from contaminated areas.

Blackberries, mushrooms, and medical herbs were chosen for analysis because they are both plentiful and susceptible to the effects of radioactive contamination. The transition coefficient presented in these tables was designed to give a "density rating" by converting measurements taken in square meters to more useful kilograms. The specific activity for Cs^{137} is listed in becquerels per kilogram, with a level of confidence as shown.

Table 1-12. Contamination of forests by Cs^{137}.

Region	Year	Total area of forest hector x 10^3	Studied Area	Levels of Contamination Ci/km^2) <1.0	1.0-2.0	2.01-5.0	5.01-10.0	10.01-15.0	15.01-40.0	40.01-80.0
Zhyto-mir	1990	735.14	735.14	251.01	188.78	201.50	-	69.05	16.79	7.83
	1991	732.36	732.36	293.03	182.49	187.41	21.22	16.43	27.02	4.76
Kiev	1990	940.57	940.57	107.07	149.93	67.10	-	13.57	2.09	0.81
	1991	427.77	427.77	241.23	107.47	52.36	15.25	5.11	3.54	2.81
Rovno	1990	549.96	549.96	35.40	279.60	218.10	-	16.86	-	-
	1991	671.53	671.53	293.57	215.29	151.61	10.79	0.33	-	-
Cher-nigov	1990	276.40	276.40	187.91	33.99	47.70	-	6.80	-	-
	1991	988.93	988.93	919.35	43.23	22.79	2.70	0.80	.06	-
Cher-assy	1990	46.25	46.25	21.50	17.10	6.20	-	1.45	-	-
	1991	220.35	220.35	190.06	22.59	6.90	0.76	0.04	-	-
Vin-nitsa	1990	77.80	77.80	77.80	-	-	-	-	-	-
	1991	216.34	211.34	179.43	25.07	6.20	0.42	-	-	-
Volyn	1990	-	-	-	-	-	-	-	-	-
	1991	173.07	173.07	131.52	36.70	4.85	-	-	-	-
Total in 10^3 Hec-tors	**1990**	**2026.12**	**2026.1**	**680.69**	**669.40**	**540.61**	**-**	**107.7**	**18.88**	**8.64**
	%Area			**33.60**	**33.00**	**26.70**	**0.00**	**5.31**	**1.00**	**<1.00**
	1991	**2839.58**	**2825.1**	**1648.2**	**632.84**	**432.12**	**51.08**	**22.71**	**30.62**	**7.57**
	%Area			**58.34**	**22.40**	**15.29**	**1.80**	**<1.00**	**1.08**	**<1.00**

Table 1-13. Concentration of Sr^{90} and Pu in 1991 Kiev foliage.

Location	Weight of dry sample	Weight of ash	Sr^{90} (Bk/kg)	Pu (Bk/kg)
Leningradskaya square	987 gr	120 gr	2.5-22.9	0.03-0.10
Lesnoy district	638 gr	67 gr	4.6-49.4	0.05-0.22
Hydropark	836 gr	90 gr	-	0.05-0.39

Note: Free-in-Air: Pu = 10-70 Bk/m^3 or 10^{-13} to 10^{-12} Ci/liter

Table 1-14. Contamination of Cs^{137} in berries, mushrooms, and medical herbs.

	Contamination in Ci/km^2				
	<=2	2-5	5-10	10-15	15-20
Number of tests-Blackberries	19	11	10	8	6
Specific activity of Cs^{137}	364 +/- 64	1029 +/- 189	1776 +/- 189	7949 +/- 1361	8222 +/- 2950
Transition coefficient	0.49	0.92	0.67	1.86	0.91
Number of tests-Mushrooms	41	33	14	17	8
Specific activity of Cs^{137}	326 +/- 224	2998 +/- 548	4997 +/- 675	19990 +/- 3800	97211 +/- 9214
Transition coefficient	1.12	2.70	1.91	3.15	4.10
Number of tests-Herbs	23	30	12	2	2
Specific activity of Cs^{137}	768 +/- 182	1840 +/- 496	1929 +/- 720	12256 +/- 897	18442 +/- 3141
Transition coefficient	1.06	0.99	1.04	2.21	1.25

Note: Transition Coefficient = dm^2 / kg = decimeter^2 / kilogram = density

Table 1-15. Contamination of Cs^{137} in wood.

	Contamination in Ci/km^2			
	<=2	2-5	5-10	10-15
Number of tests-wood with bark	26	26	20	7
Specific activity of Cs^{137}	171 +/- 29	503 +/- 91	1094 +/- 112	2674 +/- 394
Transition coefficient	0.23	0.27	0.28	0.48
Number of tests-wood without bark	21	25	9	-
Specific activity of Cs^{137}	57 +/- 10	181 +/- 40	608 +/- 147	-
Transition coefficient	0.08	0.09	0.16	-

Note: Transition coefficient = dm^2 / kg = decimeter^2 / kilogram = density

Seven years after the Chernobyl accident, approximately 7,000 people had died as a result of radiation-related illnesses. In 1988, 35% of the adult population and 43% of children were considered healthy in the Kiev region (Awramenko, 1992). In 1989, these figures were substantially lower according to government sources; however, no percentages were available to substantiate this claim.

Research shows that adults suffer from heart, blood vessel, respiratory, and digestive diseases. The number of hypertensive cases has doubled, while the number of malignant tumors has increased 11.2% in the last two years (Awramenko, 1992). According to Baryahtar & Bobyleva (1991), since the accident, medical and pathology reports confirm that the number of blood diseases increased 14.3%. The number of cases of lymphatic disease increased 45.1%, acute leukemia disease increased 14%, and endocrine cases increased substantially. From 1990-1991, nephralgia doubled, while the number of nervous system disorders increased 10 times among adults and 11 times among children. Children suffer from all of these diseases in addition to visual problems, inflammation of the joints, and increased infectious diseases. To the north of Kiev, closer to the accident site, the number of children with infectious diseases increased four times since the accident and is 96% higher than other regions of the country. Of that number, 59% suffer from anemia, which has increased 5 - 10 times among children since the Chernobyl accident.

The thyroid gland is especially sensitive to radioactive iodine found in nuclear contamination. Many adults and children received equivalent doses of over 200 rems. Goiter among children increased three times between 1989-1991, and hypothyroidism increased six times for the same period. Thyroid cancer among children has increased from 24 cases in 1990 to 70 cases in 1991.

Prior to 1991 there were no cases of internal organ cancers among children, yet today it ranks as the second largest cause of infant mortality. In 1991, 37.1% of newborns evidenced some kind of pathology and in Kiev there were 2,500 premature deliveries. Anemia increased four times among pregnant women post-Chernobyl.

According to Ukrainian law, individuals who were employed at Chernobyl and those involved in the clean-up efforts were divided into five categories depending on the amount of radiation absorbed. Category I individuals were assigned to Chernobyl when the accident occurred and received at least 25 Gy of radiation. Category II were men who were assigned clean-up duties who also received 25 Gy or more of radiation. Category III were individuals who received between 10 and 24.9 Gy of radiation. Category IV were individuals who received between 5.0 and 9.9 Gy, and Category V were those individuals who received between 0.1 and 4.9 Gy. One Gy is equivalent to 100 rads.

According to the Office of Chernobyl Affairs in Kiev, the new disease rates for individuals who received at least 25 Gy has doubled over those receiving less dosages. The relationship between absorbed dose and effect has only been investigated since 1990. In 1990, it was noted that increased oncological rates were attributed to men who received 25 Gy or more and to women who received 10 Gy or more. Generally, endocrine disease rates among male clean-up crew workers increased almost 4 times the 1988 rate. The endocrine disease rate among women who received 10 Gy or more has doubled each year between 1989 to 1990. Category II personnel were 80 - 100% more likely to suffer from digestive and nervous system diseases than individuals in other categories. In the Kiev, Zhytomir, and Chernigov regions the rates for newly acquired diseases for Category V are 26.2% hematic system, 18.2% respiratory system, and 12.6% nervous and digestive system (Baryahtar & Bobyleva, 1991). The maximum disease rates are in Ivankov, Polissia, Narodichi, and Ovruch. In the Rovno region, the lowest newly acquired disease rates were reported among children born in 1984 and 1985. Disease rates for children born after the Chernobyl accident were 1.5 to 3.0 times higher than those born prior. In the same region, respiratory illness among children accounts for 25 - 40% of all new illnesses, especially among children 1 - 3 years of age where they present with respiratory problems 8 - 10 times per year. The other sixty percent of children present with thyroid gland problems. Anemia has increased among children 2.5 to 3.2 times between 1985 and 1988.

Ukrainian law also divides people who suffered from Chernobyl into another five-group categorization. Group A includes 5,237 disabled individuals, 187 people diagnosed with acute radiation symptoms, and 15,000 people who suffered diseases directly attributed to the Chernobyl accident. Group B includes 180,000 personnel who took part in the clean-up efforts, 130,000 people who received doses in excess of 250 mSv and were relocated from areas inside the 30 kilometer zone, and 12,000 children born to parents involved in the clean-up effort. Group C includes children who have thyroid gland radiation in excess of allowable standards, 60,000 people who took part in the clean-up effort from 1988 until 1990 who received less dosages than those who were first on the scene, and approximately one million people who currently live in contaminated areas but who await relocation. Among them are 350,000 children, 65,000 of whom were born after the accident. Group D includes 1.5 million persons who work or live permanently in areas still receiving radio-ecological monitoring, in addition to their 400,000 children. Some government figures include in Group D all the inhabitants of the Kiev, Chernigov, and Zhytomir regions, or approximately another 4.5 million people.

In 1990, the fifth group was added, comprised of women, when it was realized they showed the highest rates for new respiratory and digestive systems diseases for ages of 30 - 39. Today, the Ukrainian registry contains the names of 347,619 civilians who suffered direct medical problems as a result of Chernobyl, plus 36,000 military personnel who were also affected.

Table 1-16 (Awramenko, 1992) shows the newly acquired disease rates for relocated persons. These individuals lived in contaminated areas but were forced to relocate because of excessive levels of radiation. Most of these individuals belong to Group D and the majority of them have been relocated.

Table 1-16. Disease rates for relocated individuals.

Disease	1986	1990	Percent increase
Heart and blood	0.74/1000	6.94/1000	938 %
Endocrine, digestion, Immune	12.67/1000	171.11/1000	1350 %
Respiratory	23.67/1000	136.68/1000	577 %
Nervous	21.25/1000	106.28/1000	500 %

Table 1-17 (Awramenko, 1992) shows the disease rates for those people relocated to Kiev.

Table 1-17. Disease rates among individuals relocated to Kiev.

Disease	1986	1990	Percentage Increase
Endocrine system	11.79/1000	119.73/1000	1016 %
Respiratory system	26,89/1000	163.16/1000	607 %

Finally, Table 1-18 (Awramenko, 1992) shows the relative health of these four groups from 1988 to 1991. Year-to-year percentages are decreasing due to survival rate.

Table 1-18. Percentages of individuals who are considered healthy.

Groups	1988	1989	1990	1991
Group A	74.0	66.4	52.8	33.8
Group B				
Adults	61.5	44.1	35.3	28.8
Children	-	43.9	35.2	29.1
Group C				
Adults	35.4	35.4	26.0	31.7
Children	-	52.9	40.7	39.8
Group D (Only 400,000 children were tested)	-	77.7	62.9	48.5

As of January 1, 1992, 1,536,270 persons were registered by the Ukrainian government as having suffered medical problems as a result of Chernobyl. Among those were 350,225 children and 180,144 personnel assigned clean-up duties after the Chernobyl accident (Awramenko, 1992).

Seventy percent of workers in the Narodichi forest in the Zhytomir region received 0.44 rads per year of radiation, and 10% received more than 2.3 rads per year (Yakovlev, 1992). The highest content of Cs^{137} was absorbed by woodcutters and forestry workers in the Rovno region which contains two forests, the Vladimiretsky and Dubrovitsky. These workers received between 31.8 and 74.2 Bk/kg.

Ukrainian law divides all forests into four categories, dependent on Cs^{137} dose. Category I includes the Pollessky and Narodichi forests, where contamination exceeds 40 Ci/km^2. Category II contains the Dymer, Ivankov, Ovruch, Luginsk, and Slovechansky forests, where active monitoring shows contamination between 15 and 40 Ci/km^2. Category III includes forests with contamination between 5 and 15 Ci/km^2. These forests require continuous monitoring. Category IV consists of forests containing no more than 5 Ci/km^2. The Ministry of Forests in Kiev is concerned about forest workers who have monitoring and woodcutting duties in contaminated forests.

In the 10 years following the Chernobyl nuclear accident (as of 1996), the number of healthy individuals living in contaminated areas decreased from 67.1% to 33.1%. Chronic pathologies increased from 31.5% to 66.0%.

Most cases reflect pathologies of the endocrine system, blood and blood-generating systems, nervous system, and gastroenterological system.The most substantial growth of this dangerous statistics is related to young people aged 15-17 years--6.6 times normal (8.1 times for boys and 5.6 times among girls). Death rates and disability rates have increased substantially (about 2.5-3.5 times), as compared to those of people who lived in normal conditions. Pathology of the thyroid gland constitutes 72.7% of all endocrine cases for women, and 62.5% for men.

As of 1998, the official death rate among the "Eliminators" (who are still alive) is 1.8 (80% higher than normal). This is primarily due to higher incidences of cancer, diseases of blood and blood-generating organs, and pneumonia.

The present study, an ongoing longitudinal project which commenced in 1995, entails assessments of neuropsychological and physical capabilities of four independent volunteer participant groups. The control group (Controls) consists of healthy volunteers that reside outside the immediate radiation exposure area. The second group consists of "Eliminators," who are individuals who were involved in the tasks of removing nuclear debris and assisting in construction of the containment chamber for the defective reactor facility. The third group of volunteers consists of Forestry workers who perform monitoring, woodcutting, and other related activities in the Narodichi forest, which is in close proximity of Chernobyl. It is known that 70% of workers in the Narodichi forest (in the Zhytomir region) received approximately 0.44 rads per year of radiation, and 10% received more than 2.3 rads per year (Yakovlev, 1992). Finally, the fourth group is comprised of Agricultural workers from Rozumnytsia, which is approximately 150 km south of Kiev, and for whom knowledge of the level of radionuclide is known.

The instrument that was chosen to be the primary measure of cognitive performance is the Automated Neuropsychological Assessment Metrics (ANAM) Battery, which is a subset of the Office of Military Performance Assessment Technology (OMPAT) Tester's Workbench (TWB). The TWB is a library of automated tests that has been constructed to meet the need for precise measurements of cognitive processing efficiency. The ANAM batteries are unique combinations of TWB tests that have been configured for neurocognitive assessment and evaluation of functioning in a variety of neuropsychological domains. Many of the component tests in ANAM were derived from the Unified Tri-Service Cognitive Performance Assessment Battery (UTCPAB; Reeves et al. 1991) and the Walter Reed Performance Assessment Battery (Thorne et al. 1985). The Ukrainian subset of ANAM (ANAMUKR) was designed by Reeves and Gamache (1994), and constitutes a specialized subset of the TWB-ANAM batteries. It consists of tests that have been configured for repeated measures testing for neurocognitive impairment due to exposure to radionuclides. It has been designed to assess levels of neurocognitive function ranging from superior to moderately impaired. ANAMUKR subtests also include a stand-alone module for assessing sustained attention (Running Memory Continuous Performance Test).

In the present study, the ANAMUKR battery was combined with the Gamache Physical Abilities Battery (GPAB; Gamache, 1993), for testing the physical capabilities of individuals exposed to radionuclides. This battery, composed of tests derived from Fleishman and Quaintance (1984), is especially sensitive to the physical decrements in performance resulting from exposure to radionuclide contamination. The GPAB consists of tests designed to measure explosive strength (broadjump), static strength (carrying weight), dynamic strength (squat thrusts), and gross body equilibrium (balance beam).

In this report, we describe data on the GPAB and ANAMUKR obtained from four independent groups from Ukraine in 1995 (initial test), and in 1996,1997, and 1998 (repeated tests). These data provide a reference point from which to gauge physical and cognitive performance of individuals who may or may not have been exposed to varying levels of ionizing radiation resulting from the nuclear accident at Chernobyl in 1986.

SECTION 2
METHOD

2.1 PARTICIPANTS.

The participants in the initial phase of the study consisted of 127 volunteers (24 females, 103 males) who lived in Ukraine prior to 1986. Ages ranged from 11-61 years, averaging 40.21 years. The four groups into which they were divided included a non-exposed Control group (*AC*); and three exposed (exposure) groups: Eliminators (*AE*), Forestry Workers (*AF*), and Agricultural Workers (*AG*). Demographic information is presented in Table 2-1. Mean dose levels of exposure to radiation (in rads) for each group are included; these are based on the medical records of the individuals.

Table 2-1. Demographic information and mean dose of radiation for the 4 groups – above background radiation.

GROUP →	*AC* (n=31)	*AE* (n=36)	*AF* (n=29)	*AG* (n=31)
Age **Mean (S.D.)**	33.23 (7.86)	40.47 (6.81)	50.83 (7.83)	36.32 (14.26)
Gender **Male** **Female**	 24 7	 33 3	 29 0	 17 14
Mean dose In rads (FIA)	0	62.95	12.61	8.81

These individuals were randomly assigned to their groups, which were counterbalanced by occupation. Further, participants in the control group were assigned to match by occupation, as closely as possible, the exposure participants. For example, if there was a truck driver in any of the three exposure groups, a truck driver was sought as a control. In addition, participants in the control group were matched for age and gender to those in the exposure groups.

2.2. INSTRUMENTS.

2.2.1. Gamache Physical Abilities Battery (GPAB).

Physical testing involved two stations, each equipped with a stop watch and tape measure. Three tests were timed with a stopwatch: balance beam, squat thrusts, and carrying weights. A description of each test in the GPAB is presented in Table 2-2.

Table 2-2. Description of Gamache Physical Abilities Battery (GPAB).

Test	Measurement	Apparatus
Broad jump **(BROADJMP)**	Distance covered in one broad jump (meter)	Designated starting point. Tape measure.
Carrying weight **(CARRYWGT)**	Distance covered in 30 sec. (meter)	10-meter course. participants run back and forth in straight lines carrying 15 kilograms of sand (men) or 10 kilograms (women, children). Tape measure, stop watch, buckets of sand
Squat thrusts **(SQUATTHR)**	Number of squat thrusts in 2 min.	Any area where squat thrusts can be don. stop watch
Balance beam **(BALBEAM)**	Distance covered in 20 sec. (meter)	4-meter board, 12 centimeters wide, 15 centimeters from ground. Tape measure, stop watch.

All physical test scores were recorded in laboratory notebooks. Two observers participated as test administrators for the physical abilities battery. One administrator read instructions to participants and ensured their understanding. The other timed and/or took measurements as appropriate for each test. Independent observer confirmation was required prior to recording scores. All subjects were tested according to standard procedures, with one exception. The hospital where the eliminators resided did not allow buckets of sand on the premises. Therefore, hand-held weights equivalent to the weight carried by other groups were substituted.

2.2.2 Automated Neuropsychological Assessment Battery-Ukraine (ANAMUKR).

The tests in the ANAMUKR battery includes the Stanford Sleepiness Scale (**SLP**), Code Substitution (visual search, immediate recall, and delayed recall: **CDS, CDI, CDD**), Running Memory Continuous Performance Task (**CPT**), Digit Symbol (**DGS**), Matching to Sample (**MSP**), Spatial Processing (**SPD**), Simple Reaction Time (**SRT**), Tapping-Right and Left Index Fingers (**TAPR & TAPL**), and Two-choice Reaction Time (**2CH**). These subtests of ANAM have been described previously (Reeves & Winter, 1992; Levinson & Reeves, 1994). Each session required approximately 60 minutes.

2.3 ASSESSMENT SITES AND ENVIRONMENTS.

Participants in the Control group resided in Ternopil (pop. 250,000). This city is located approximately 450 km west of Kiev, the capital of Ukraine. All testing was conducted in High School Number 22 (Fig. B-7). The Eliminators were tested in the Ukrainian Center for the Radiation Protection of the Population, which is essentially a hospital environment (Fig. B-3). This special hospital is in the suburbs of Kiev, and was established to attend to the medical needs of these individuals. The Forestry Workers were tested in the Ovruch forest, approximately 250km northwest of Kiev. All testing was conducted in their barracks (see Fig. B-8). The Agricultural workers were tested in the village of Rozumnytsia, in the Kiev region, approximately 150 km south of Kiev. The testing site was a farmhouse (Figs B-4, B-5, B-6).

2.4 PROCEDURE.

On days assigned to specific groups, researchers prepared the testing site by installing laptop computers for administration of the ANAMUKR battery (Fig. B-4), and by setting up the apparatus for administration of the physical abilities test battery. A table and two chairs were situated at each of three ANAMUKR testing stations. Each participant sat in one chair and the test administrator sat in the other. This enabled the administrator to ensure that the participant understood instructions and was prepared for testing. Participants were instructed to ask as many questions as necessary to ensure full understanding prior to testing. One table was placed at the entrance for participant registration and orientation, which included having each participant read and sign an informed Consent Form in Russian and English (see Appendix C –only the English version is shown).

During periods when all computer test stations were occupied, participants first completed the GPAB. The rotation of physical testing (i.e., order of balance beam, squat thrusts, etc.) was randomized to the extent that space was available. A rest area was established for participants while awaiting further testing. During test sessions the administrator ensured that there was no discussion among participants about up-coming tests. At the conclusion of the testing sessions, all participants were thanked and given the equivalent of two USA dollars.

The ANAM battery test scores were stored on the hard disk drive of each computer. At the end of the day, all scores were copied to backup 3 ½" floppy disks and marked for that group and year of testing. The backup disks were then re-copied to a second diskette.

Participants in the four groups were tested on the GPAB and ANAMUKR in 1995, 1996, 1997, and again in 1998. All 1995 measures were deemed valid, as were the 1996 GPAB data obtained on the Controls.

Due to extraneous factors, a major portion of the 1996 ANAMUKR data obtained from the Controls was not valid. As a result, these data were not included in analyses of the 1996 ANAMUKR results. Instead, all analyses of the 1996 ANAMUKR performances of the exposure groups relative to the Controls were based on the 1995 Control data. Further, the 1996 GPAB data from the Controls were virtually identical to those obtained in 1995.

Therefore, the same procedure was used in analyses of the 1996 GPAB performances of the exposure groups relative to those of the Controls; i.e., 1995 Control data were also used for these comparisons. For the same reasons, similar analyses were performed on the 1997 and 1998 data. However, for purposes of data analyses based on 4-year averages, all data from all groups were used.

SECTION 3
RESULTS

3.1 OVERVIEW OF 4-YEAR RESULTS: 1995-1998.

The ANAM data files were first consolidated in a computerized spreadsheet and then inspected for completeness and invalid data. Invalid data were defined as "premature responses" which occurred in less than 100 ms, and/or an inordinate number of lapses which indicated that the participant did not understand the instructions for a test prior to administration. This initial screening resulted in unequal numbers of participants associated with each test, but it ensured that the preliminary data presented herein were derived from complete and valid test administrations.

An ANOVA revealed a significant age difference among the groups. Subsequent Scheffe tests indicated that this was due to the higher ages of Group ***AF***, as this group differed significantly from each of the others. No other significant differences in age were observed. Gender composition of the four groups also significantly differed, as revealed by results from a Chi-square test. This is most likely a result of the higher number of females in Group ***AG***, as none of the other groups differed from each other: all were predominantly male. Possible differences between the ***AC***s and ***AE***s on the demographic variables were of particular concern, but none were revealed.

Analyses of 4-year averages for all groups on all measures were performed so as to obtain an overview of how the exposure groups performed relative to the controls on the physical and cognitive measures. Multivariate analyses of variance (MANOVAs) revealed significant differences among the 4 groups on ***all*** measures; further, pairwise comparisons indicated that with only a few exceptions, the average levels of performance of the exposure groups were significantly lower than those of the controls.

Graphic illustrations of actual performance levels of the exposure groups on each task across the 4 years are presented in Figures 3-30 through 3-53, in the section describing the 1998 retest. In each figure, the 4-year averaged performance level of the controls is used as a referent; it is denoted by a dotted line (typically across the top) on each figure.

3.1.1 GPAB.

The 4-year averages for the 4 groups on the physical tasks are presented in Table 3-1. The difference among the groups on **BRODJMP** was significant at the .01 level, while the other differences were significant at the .001 level. Pairwise comparisons of the 4-year averages revealed that with only one exception, all exposure groups performed at significantly lower levels than the controls. The 4-year averages for all groups on all GPAB tasks are graphically illustrated in Figures 3-1 through 3-4.

Table 3-1. Four-year averaged performance on GPAB: physical tasks.

GROUP → TASK	*AC*	*AE*	*AF*	*AG*
BRODJMP (meters)	1.59	1.33	1.43	1.50*
CARRYWGT (meters)	51.61	30.96	40.45	42.51
SQUATTHR (number)	66.66	21.24	40.35	48.41
BALBEAM (meters)	22.19	15.96	20.26	19.13

Note: *not significantly lower than controls.

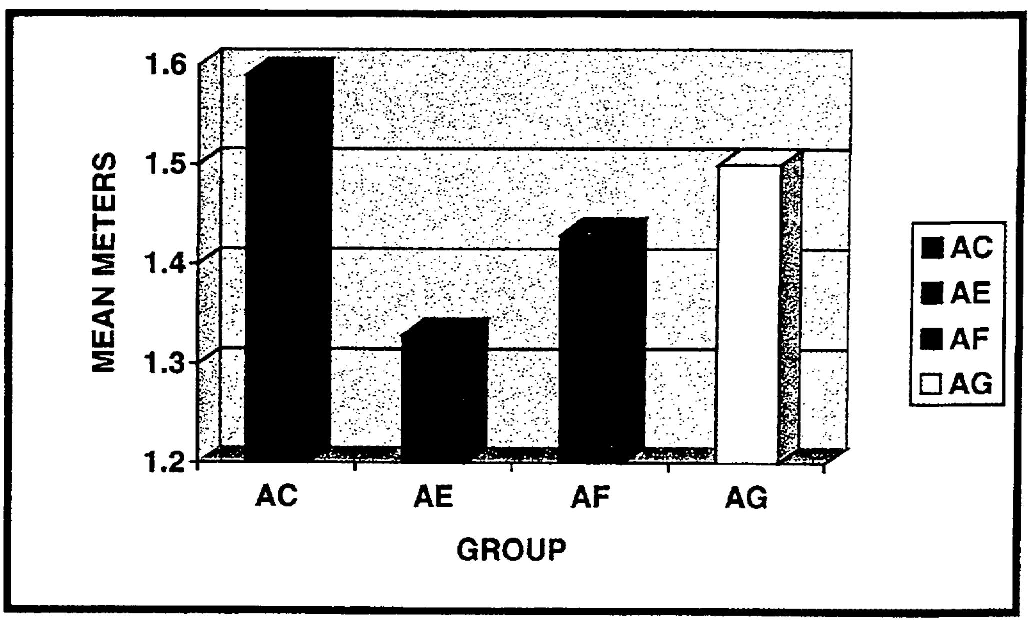

Figure 3-1. 4-year averaged performances on GPAB: BROADJUMP.

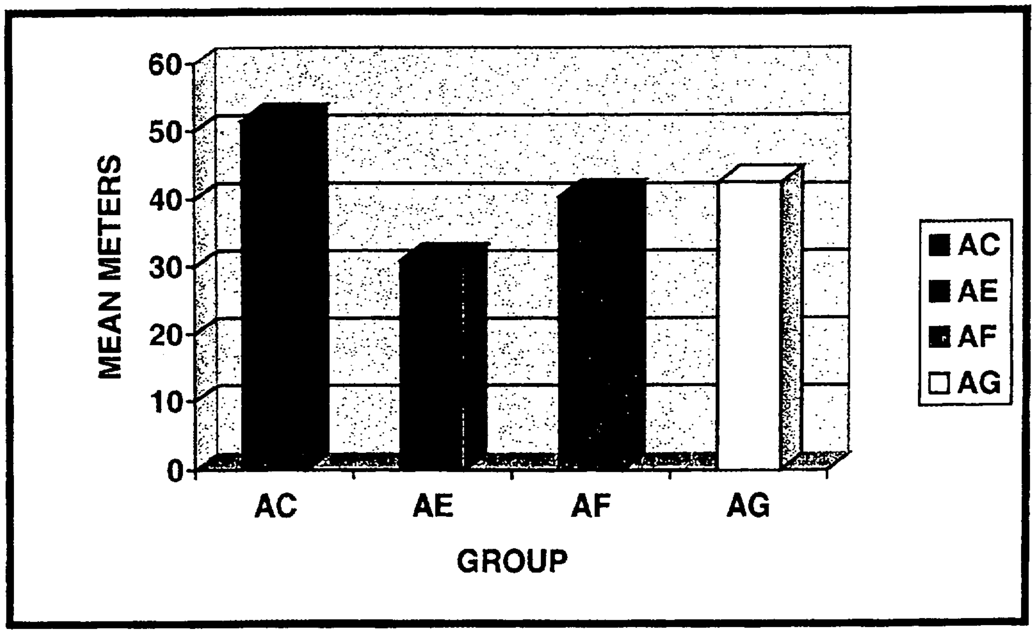

Figure 3-2. 4-year averaged performances on GPAB: CARRYING WEIGHT.

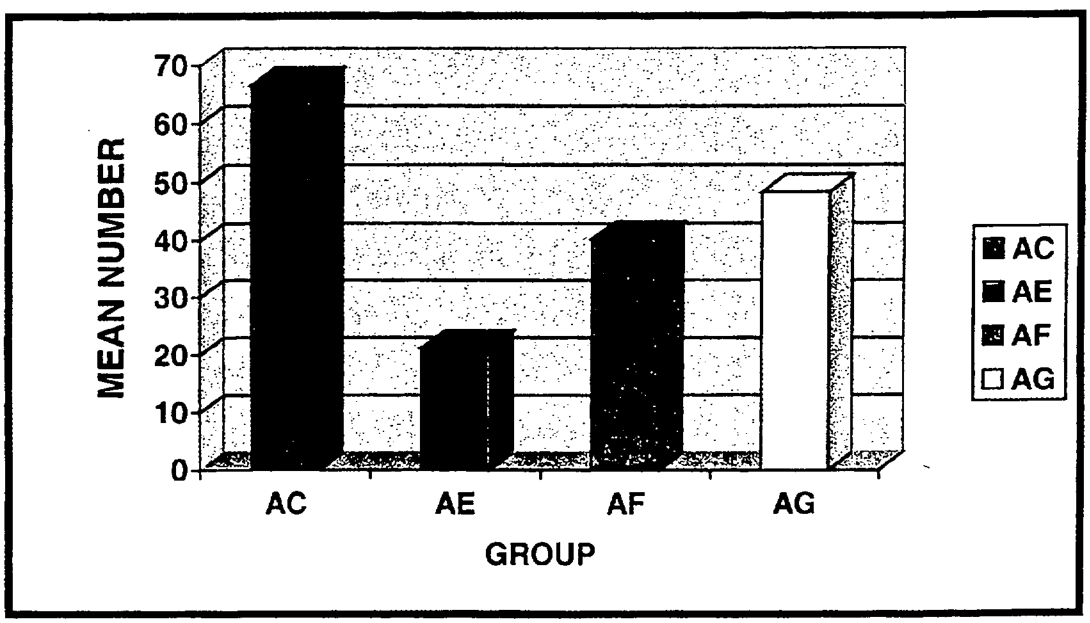

Figure 3- 3. 4-year averaged performances on GPAB: SQUAT THRUSTS.

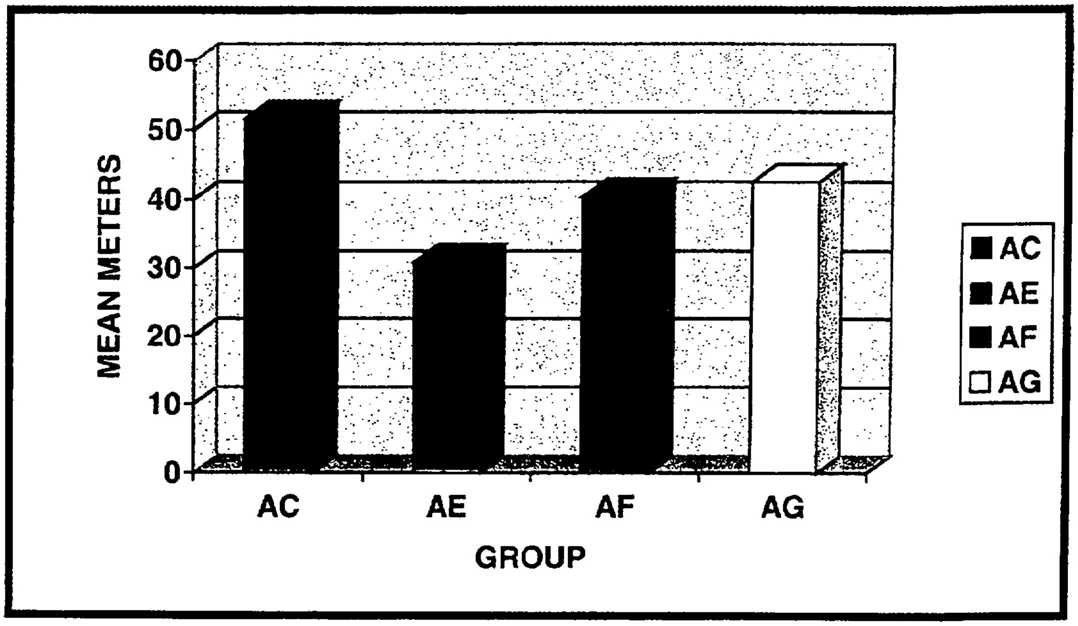

Figure 3-4. 4-year averaged performances on GPAB: BALANCE BEAM.

3.1.2 ANAMUKR: Accuracy.

The 4-year averages for the 4 groups on ANAMUKR-accuracy are presented in Table 3-2. Table 3-2 represents the percentage of correct responses. All differences among groups were significant at the .001 level. Pairwise comparisons of the 4-year averages revealed that, with only 3 exceptions, the exposure groups performed at significantly (most at .001) lower levels than the controls. Figures 3-5 through 3-12 graphically illustrate these findings.

3.1.3 ANAMUKR: Efficiency.

The 4-year averages for the 4 groups on ANAMUKR-efficiency are presented in Table 3-3. Table 3-3 represents correct responses per minute. All differences among groups were significant at the .001 level. Pairwise comparisons of the 4-year averages revealed that, with only 1 exception, the exposure groups performed at significantly (most at .001) lower levels than the controls. Figures 3-13 through 3-21 graphically illustrate these findings.

3.1.4 ANAMUKR: Additional Measures.

Performances averaged over 4 years on the tapping task (right, left), and on the sleepiness scale are presented in Table 3-4. Although all group differences were significant at the .001 level, the levels of the agricultural workers did not differ from those of the controls on any of these measures. The tapping rates for the other exposure groups were significantly (.001) lower that those of the controls, and levels of sleepiness were significantly higher for the Eliminators. These findings are graphically illustrated in Figures 3-22 through 3-24.

Table 3-2. 4-Year averaged performances on ANAMUKR: Accuracy (Percentage of correct responses).

GROUP → TASK	*AC*	*AE*	*AF*	*AG*
2CH	97.36	92.76	92.91	93.98
CDS	96.17	91.14	90.66	95.18*
CDI	91.42	***<u>73.50</u>***	***<u>80.49</u>***	89.01*
CDD	89.24	***<u>72.35</u>***	***<u>78.99</u>***	85.32
CPT	93.66	***<u>77.06</u>***	***<u>86.08</u>***	89.72
DGS	87.96	***<u>73.00</u>***	81.32	80.40
MSP	92.88	***<u>75.33</u>***	84.22	87.68
SPD	88.21	81.18	83.96	91.94*

Note: *not significantly lower than controls. Italicized, bolded, and underlined numbers are considered to suggest clinically meaningful impairment.

Table 3-3. 4-Year averaged performances on ANAMUKR: Efficiency (Correct responses per minute).

TASK / GROUP →	*AC*	*AE*	*AF*	*AG*
SRT	163.51	***111.58***	***111.67***	147.24
2CH	110.62	***76.42***	***80.95***	101.27
CDS	39.58	***24.22***	***26.12***	34.33
CDI	36.42	***18.76***	***24.07***	29.46
CDD	38.19	***20.77***	***26.46***	31.57
CPT	85.22	***58.22***	71.69	79.00
DGS	36.19	***24.28***	30.54	29.30
MSP	38.63	***20.23***	***24.56***	30.31
SPD	27.67	***19.11***	22.81	26.38*

Note: *not significantly lower than controls. Italicized, bolded, and underlined numbers are considered to suggest clinically meaningful impairment.

Table 3-4. 4-Year averaged performances on ANAMUKR: Additional measures.

TASK / GROUP →	*AC*	*AE*	*AF*	*AG*
TAP-R (Mean number of responses in 10 seconds)	57.57	***47.00***	***49.20***	55.23*
TAP-L (Mean number of responses in 10 seconds)	51.50	***41.23***	***42.63***	48.70*
SLP (Scores from 1-7)**	1.63	***2.46***	1.77*	1.69*

Note: *not significantly different than controls.
**higher score = more sleepy. Italicized, bolded, and underlined numbers are considered to suggest clinically meaningful impairment.

3.1.5 A Clinical Neuropsychological Interpretation of Chernobyl-ANAM data.

Overall results from the 4-year averages of ANAM test results, presented in Tables 3-2 through 3-4, provide evidence of clinically meaningful neurocognitive impairment associated with the Eliminator and Forestry groups. The Agricultural group was generally comparable to the Control group. Their test performance did not reveal any meaningful evidence of neuropsychological impairment, and scores were generally within normal limits.

With respect to the Eliminator and Forestry groups, it appears that they have clinically significant neuropsychological deficits in several areas. These include deficits in the ability to sustain high levels of attention/concentration, to encode new information (i.e., learning ability), working memory (i.e., the ability to hold new information in memory for short periods of time), mental flexibility (i.e., the ability to shift mental sets rapidly), and psychomotor speed. The Eliminators are suffering the most severe impairment of neurocognitive and psychomotor abilities. Their test scores revealed impairment of mental power (the ability to produce correct responses to test items) and neurocognitive efficiency (the ability to do both quickly and accurately). In this study mental power was indexed by using percent accuracy scores, which are presented in Table 3-2. Neurocognitive efficiency was indexed by the ANAM "thruput" score, which literally translates to "number of correct responses per minute." These data are presented in Table 3-3. Psychomotor speed data are presented in Table 3-4. These data represent the average number of "Finger Taps" a subject is able to make on a mouse key during 5 consecutive 10 second response trials. Finally, each subject's fatigue level was measured by a Sleepscale score that ranges from 1=very alert and energetic to 7=sleep onset soon. A summary of clinically meaningful deficits for the eliminators is presented below.

3.1.5.1 **Learning and Memory.** The Code Substitution, Learning, Immediate, and Delayed recall subtests were the primary instruments for assessing a subject's ability to learn and retain new information. This test entails having the subjects learn 8 pairs of associated digits and symbols. Following the learning trial, subjects are required to demonstrate the ability to remember the correct pairings immediately and then after a delayed time interval of approximately 20 minutes. Memory scores for immediate and delayed recall trials for Eliminators were 73 & 72% respectively as compared to 91 & 89% for the controls. These results suggest that the Eliminators have an impaired ability to encode, i.e., learn and store new information in short-term memory (e.g., CDI=73%). Although their learning ability is impaired, they are still able to learn and store new information to a certain degree. Further, they are able to retain and retrieve (i.e., remember) the newly learned information over meaningful time intervals. This is indicated by a delayed recall score (i.e., CDD=72%) that nearly matches the immediate recall score (i.e., CDI=73%). These results indicate that they do NOT have a rapid rate of forgetting over retention intervals, as would be the case in Alzheimer's and Alcohol Korsakoff's Dementias. ***The implication is that observed impairments in neurocognitive and memory processes in this sample are NOT a result of chronic alcohol abuse or an Alzheimer's-like CNS disorders.***

3.1.5.2 **Attention/Working Memory.** The Digit Set Comparison Test (DGS) was the primary ANAM subtest used to assess attention and working memory. It is comparable to the traditional Wechsler Adult Intelligence Scale Digit Span subtest. The DGS requires the subject to remember a series of numbers for a few seconds and then determine if a comparison sample is the same or different.

Results from this test indicated that the Eliminators were meaningfully impaired with respect to both percent accuracy (power) and efficiency measures. For example, the Eliminators had an averaged accuracy score of 73% as compared to a Control group score of 87%. Further, the Eliminators had an averaged efficiency score of 24% vs. a score of 36% for the Controls. These results suggest that the Eliminators are experiencing significant difficulties with the ability to attend to and retain information that is not personally meaningful; even for brief periods of time.

3.1.5.3 Mental Flexibility/Executive Function. The Continuous Performance Task was the primary ANAM subtest used for assessing the ability to sustain high levels of concentration and rapidly shift mental sets. These are important "executive" functions that relate to frontal lobe functions. The test requires the subject to rapidly determine if a letter that is displayed on the computer screen is the "same or different" from the letter presented immediately before. Results from this test indicate that the Eliminators have serious deficits regarding the ability to sustain concentration and exercise mental flexibility. For example, the Eliminator's accuracy scores were 77% vs. Control's score of 93%. Further, the Eliminators' efficiency scores were 52 vs. the Control's scores of 85.

3.1.5.4 Level of Subjective Energy. The ANAM Sleep Scale was used to assess the subjects' level of fatigue...i.e., how energized or tired did they feel on a 1-7 scale. The results indicate that the Eliminators felt slightly more tired than the other groups...however, the difference was barely 1 point higher (i.e., the Eliminator average was 2.46). This means that they did not really feel tired. This suggests that observed attention and memory deficits were not due to fatigue.

3.1.5.5 Psychomotor Ability. The ANAM Finger Tapping Test was implemented as the primary test of psychomotor speed. The test requires the subject to "tap" on a mouse key as fast as possible during ten second test trials. The outcome measure is the average number of taps for a ten-second interval. The ANAM test results on this subtest revealed that the Eliminators were much slower that the other groups. For example, their averaged tapping scores for RT and LT index finger tapping were 47 & 41 vs. the Control group scores of 57 & 51. Since their subjective level of fatigue was minimal, results suggest that this psychomotor slowing was not due to being tired.

3.1.5.6 Final Conclusion. The overall results that include loss of mental power and cognitive efficiency and psychomotor slowing strongly suggest impaired brain function. The pattern of impairment is similar to that commonly associated with white matter disease (white matter disease effects the myelin sheaths as a part of neurological functioning).

3.2 CORRELATIONS BETWEEN DOSAGE OF RADIATION AND 4-YEAR AVERAGED PERFORMANCE LEVELS.

For each participant in the study, the level of radiation exposure was obtained from medical records. The original dosage presented on Table 2-1, on page 21, included all subjects. However, our statement of work specifies that the government is interested in low dosage defined as below 70 rads. Therefore we eliminated from Table 2-1 all dosages higher than 70 rads. The following reflects only those dosages less than 70 rads. Mean dosage (and standard deviation) in rads for the four groups were as follows: ***AC***: 0.00 (.00); ***AE***: 43.41 (19.82); ***AF***: 12.61 (2.10); and ***AG***: 8.81 (5.63).

Since the Controls received virtually no radiation, correlations were based only on participants in the 3 combined exposed groups for whom measures on all tasks were obtained for all 4 years of testing, excluding Eliminators receiving over 70 rads. The 4-year average for each exposed individual on each measure was calculated, and these were used to obtain Pearson correlations between each measure and dosage of radiation. In addition, standard multiple regressions were used to calculate the correlations between combined groups of tasks and dosage. The results of these analyses are presented in Table 3-5.

Table 3-5. Correlations between dosage of radiation and performance levels.

TASK	CORRELATION	SIGNIFICANCE
GPAB	**.70**	**.001**
BRODJMP	-.18	--
CARRYWGT	-.34	.01
SQUATTHR	-.55	.001
BALBEAM	-.56	.001
ANAMUKR: ACCURACY	**.71**	**.001**
2CH	-.07	--
CDS	-.38	.01
CDI	-.62	.001
CDD	-.56	.001
CPT	-.47	.001
DGS	-.35	.01
MSP	-.54	.001
SPD	-.52	.001
ANAMUKR: EFFICIENCY	**.68**	**.001**
SRT	-.25	--
2CH	-.44	.001
CDS	-.37	.01
CDI	-.50	.001
CDD	-.50	.001
CPT	-.48	.001
DGS	-.49	.001
MSP	-.45	.001
SPD	-.51	.001
ANAMUKR: OTHER TASKS		
TPR	-.34	.01
TPL	-.37	.01
SLP	.60	.001

Significant correlations were revealed for *21* of the 24 measures. The only tasks not significantly correlated with dosage were broadjump, simple reaction time, and 2-choice accuracy.

Unlike the other GPAB tasks, broadjump does not require sustained energy; therefore, it is not surprising that it is not related to dose level. The two ANAMUKR measures not related to dose are the simplest of all the tasks, requiring little effort to complete. Thus one would not expect them to be related to levels of radiation. Although tapping is also relatively simplistic, it requires fine motor coordination. Such coordination is reflective not only of integrity of the cerebral precentral gyri, but also of the cerebellum. Involvement of either of these areas would compromise the ability to perform this task.

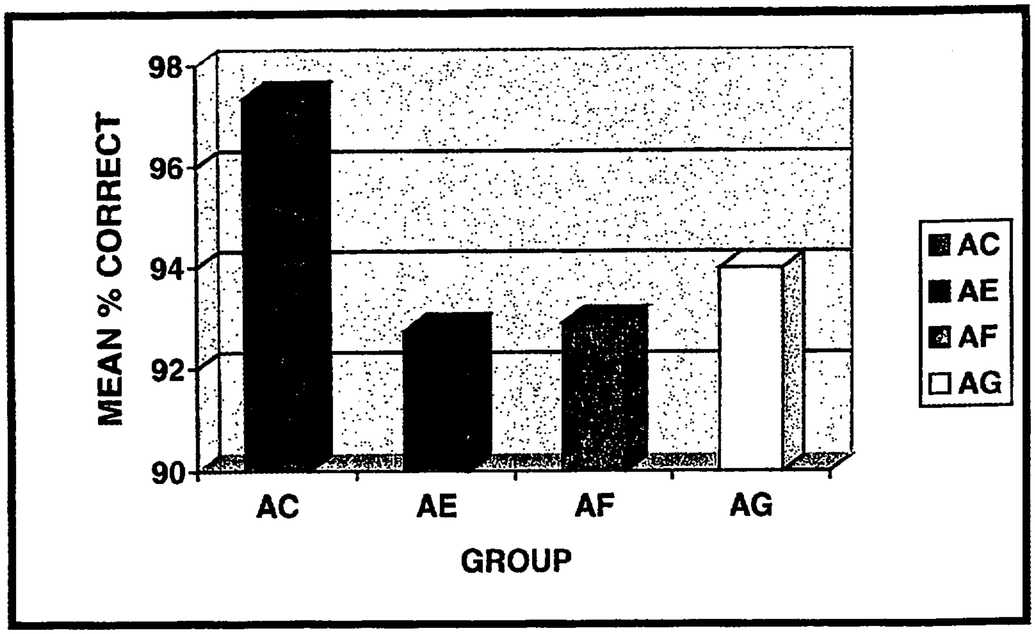

Figure 3-5. 4-year averaged performances on ANAMUKR: 2CH-ACC.

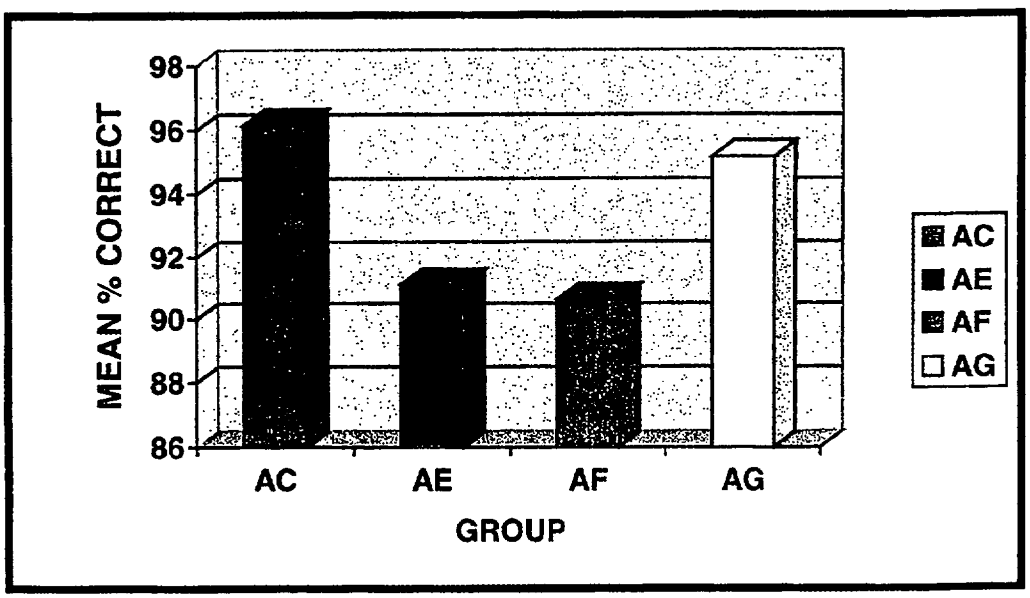

Figure 3-6. 4-year averaged performances on ANAMUKR: CDS-ACC.

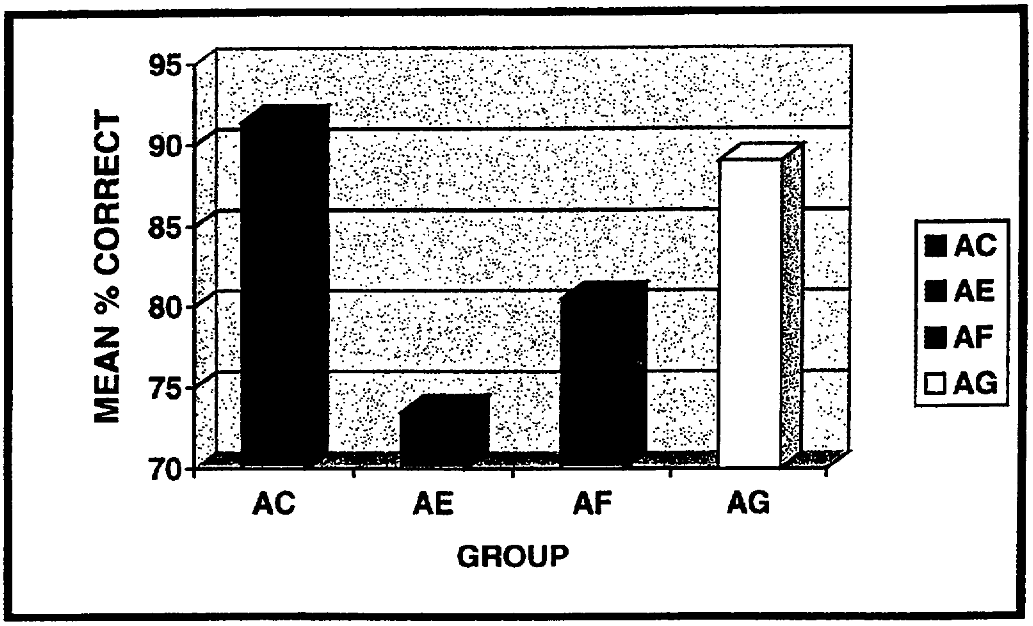

Figure 3-7. 4-year averaged performances on ANAMUKR: CDI-ACC.

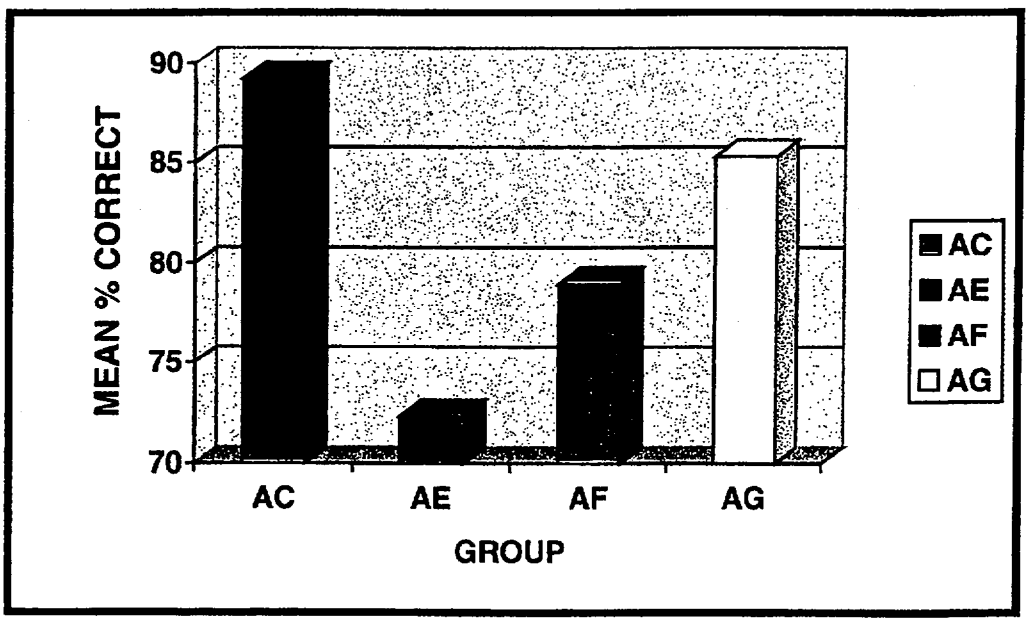

Figure 3-8. 4-year averaged performances on ANAMUKR: CDD-ACC.

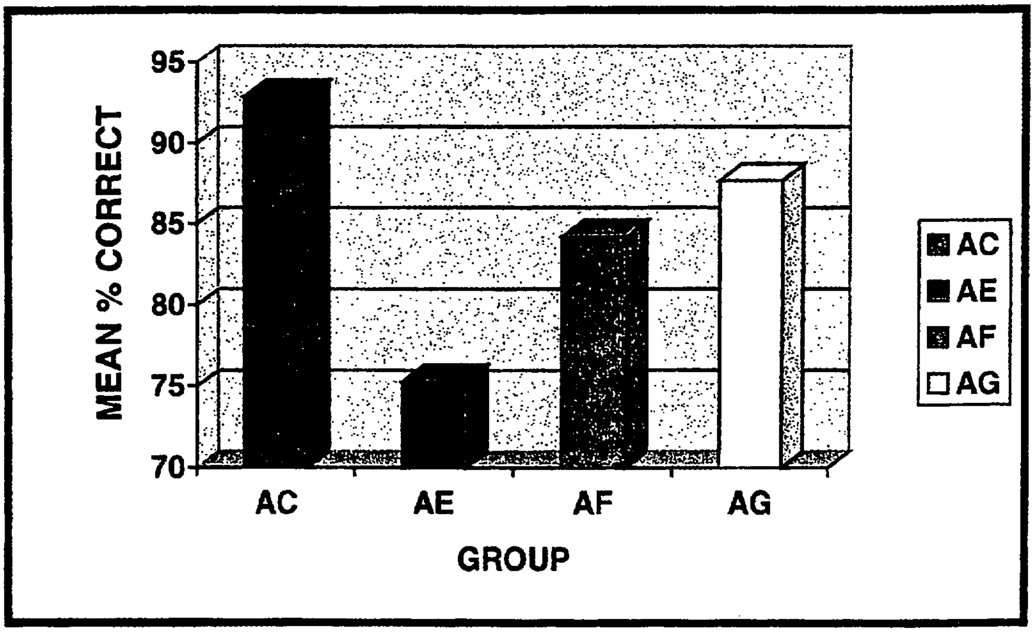

Figure 3-11. 4-year averaged performances on ANAMUKR: MSP-ACC.

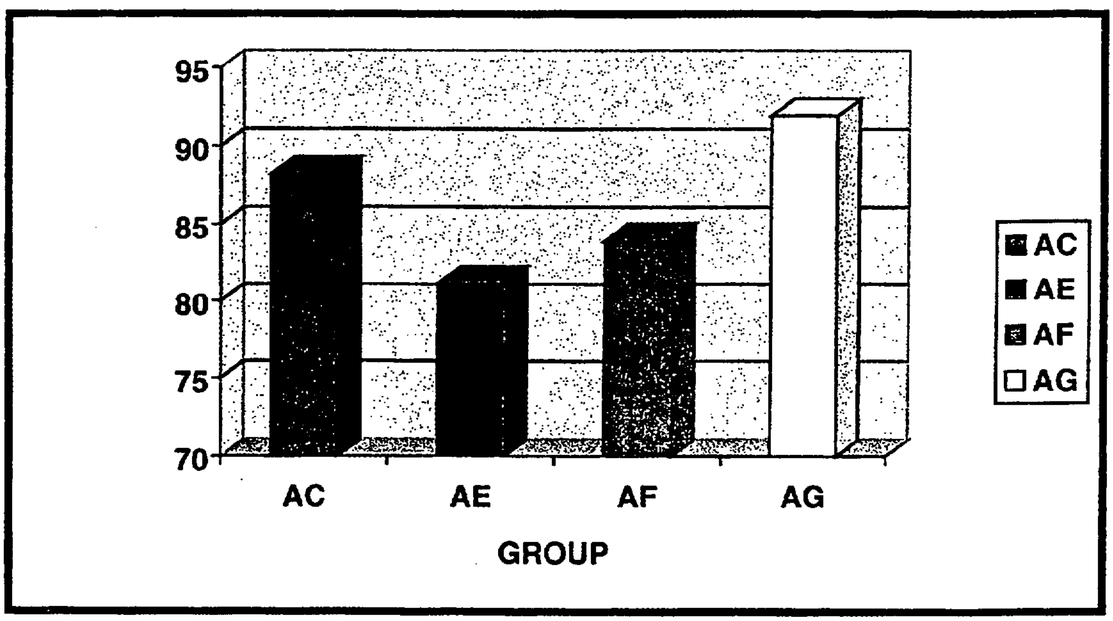

Figure 3-12. 4-year averaged performances on ANAMUKR: SPD-ACC.

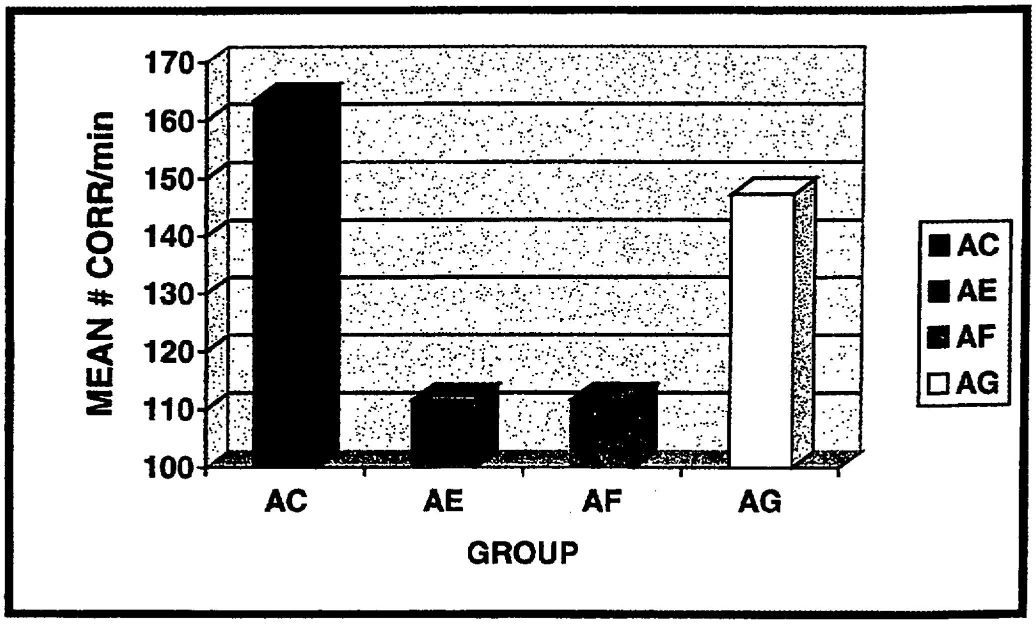

Figure 3-13. 4-year averaged performances on ANAMUKR: SRT-EFF.

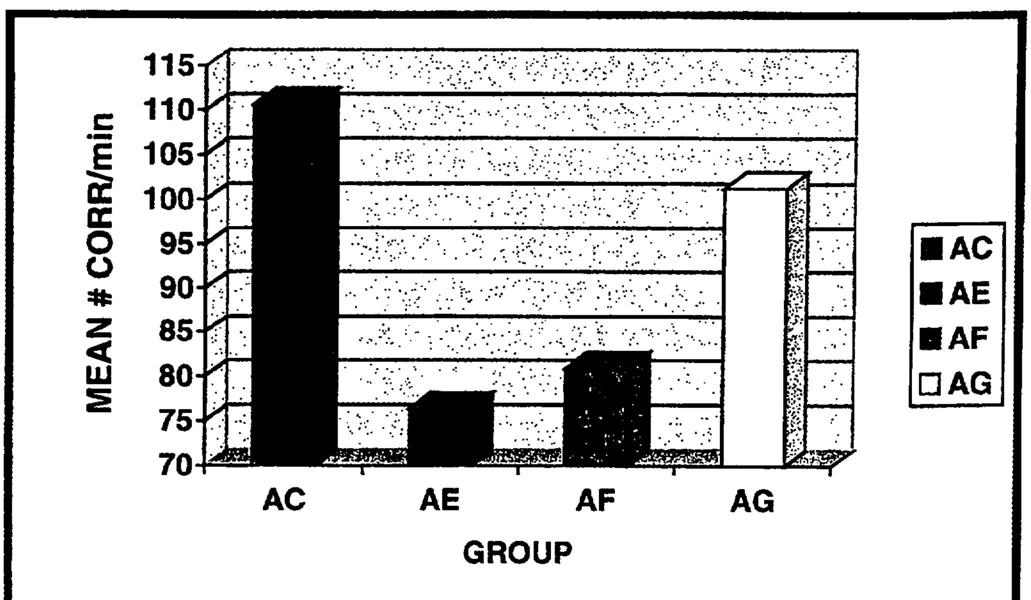

Figure 3-14. 4-year averaged performances on ANAMUKR: 2CH-EFF.

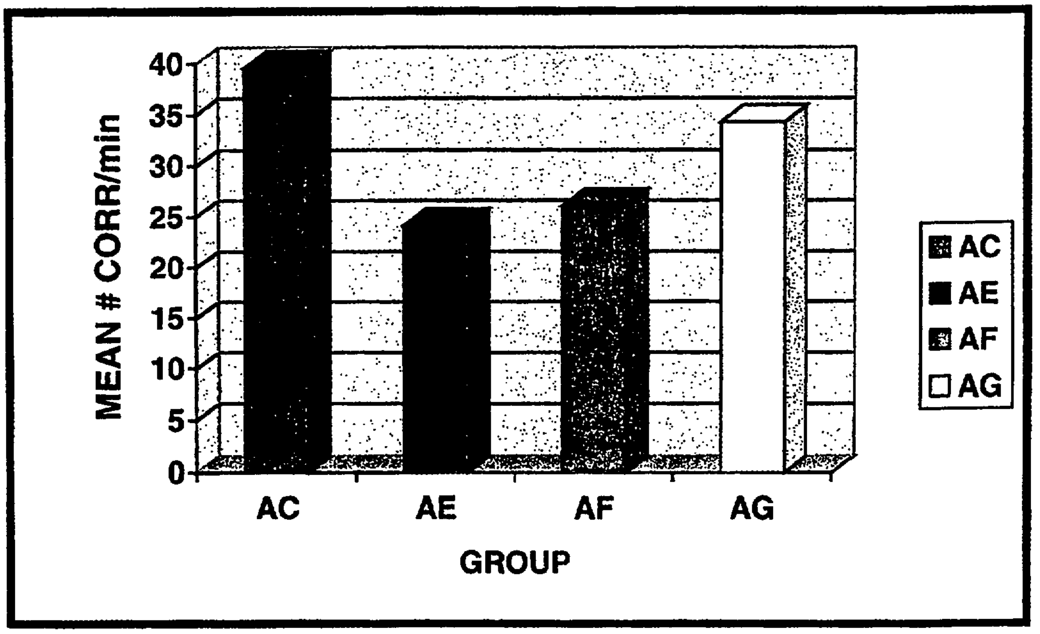

Figure 3-15. 4-year averaged performances on ANAMUKR: CDS-EFF.

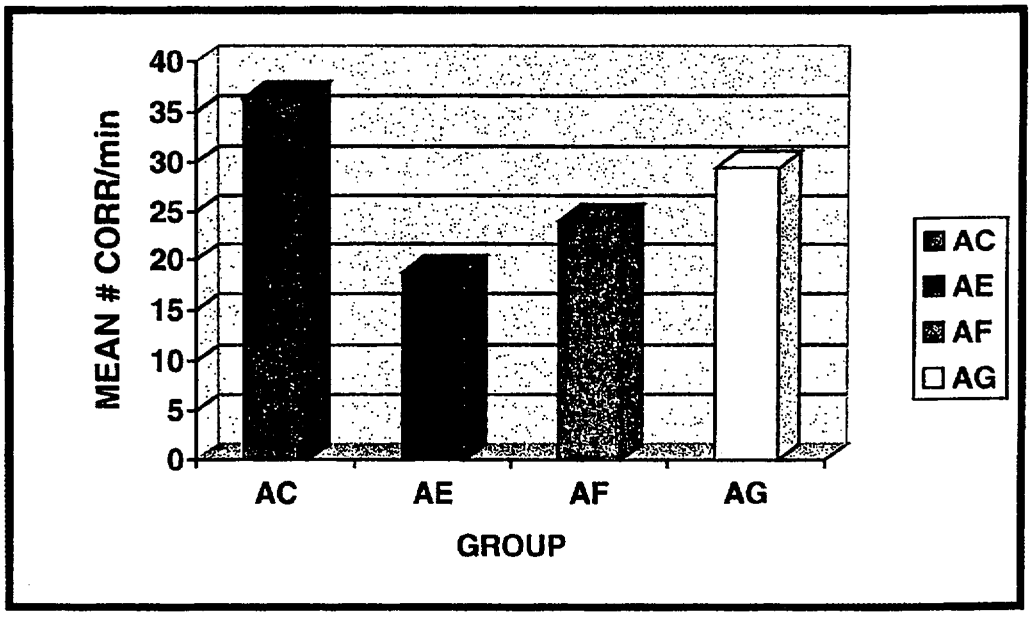

Figure 3-16. 4-year averaged performances on ANAMUKR: CDI-EFF.

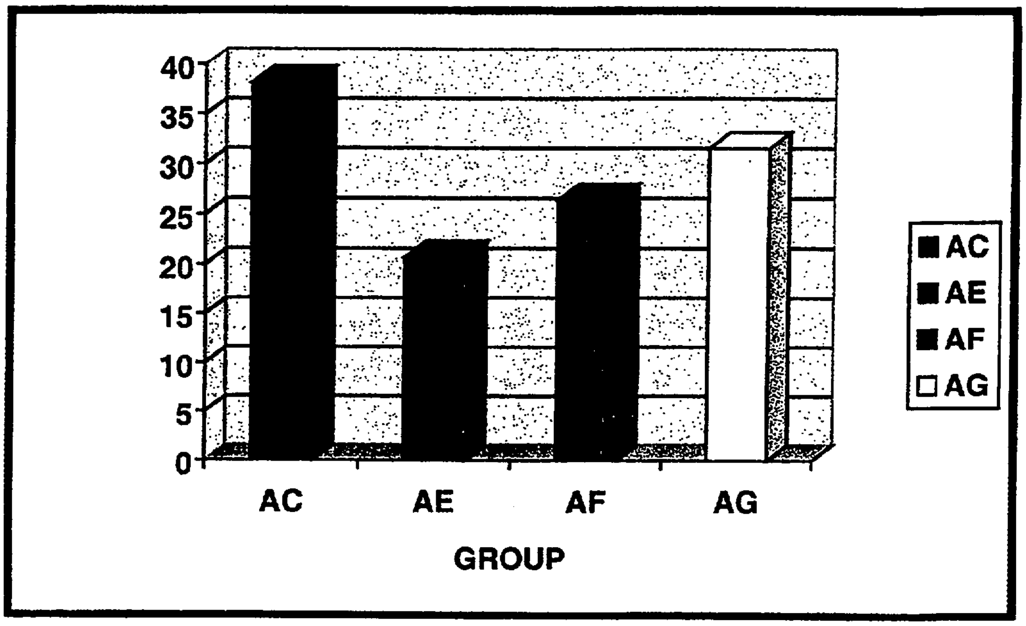

Figure 3-17. 4-year averaged performances on ANAMUKR: CDD-EFF.

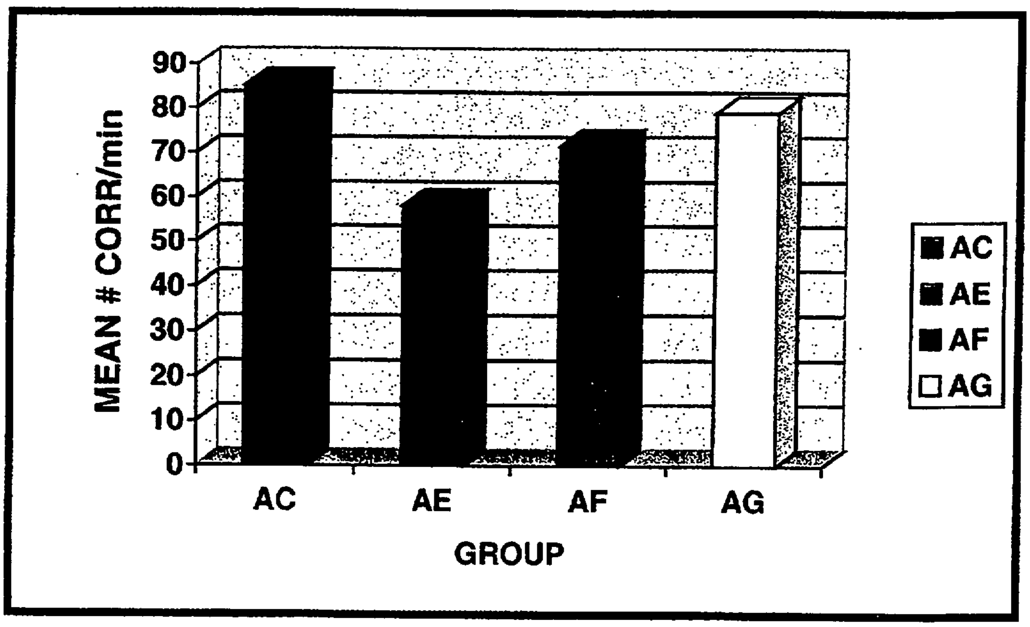

Figure 3-18. 4-year averaged performances on ANAMUKR: CPT-EFF.

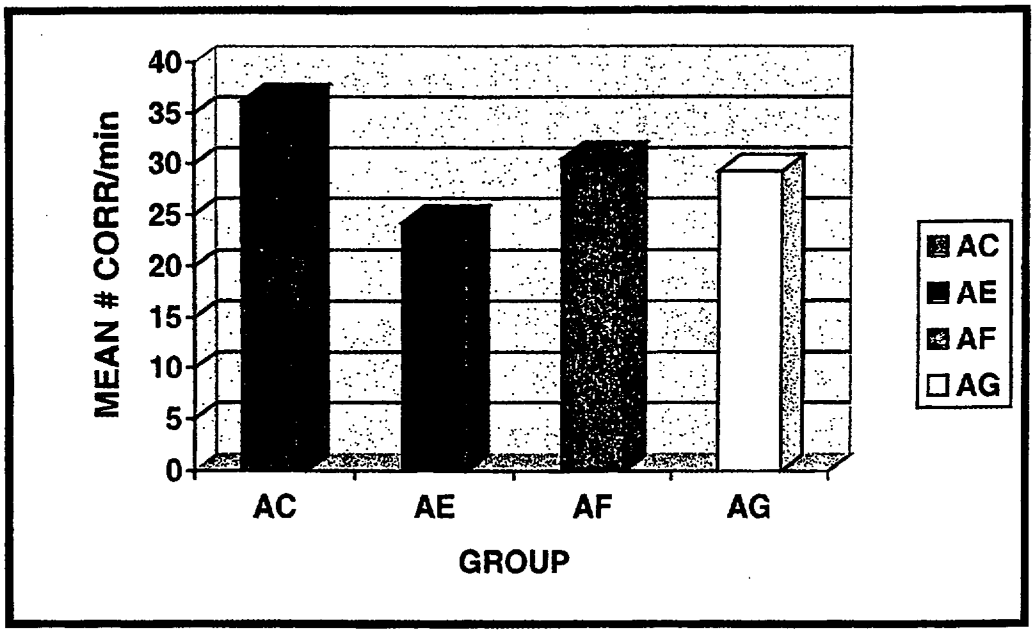

Figure 3-19. 4-year averaged performances on ANAMUKR: DGS-EFF.

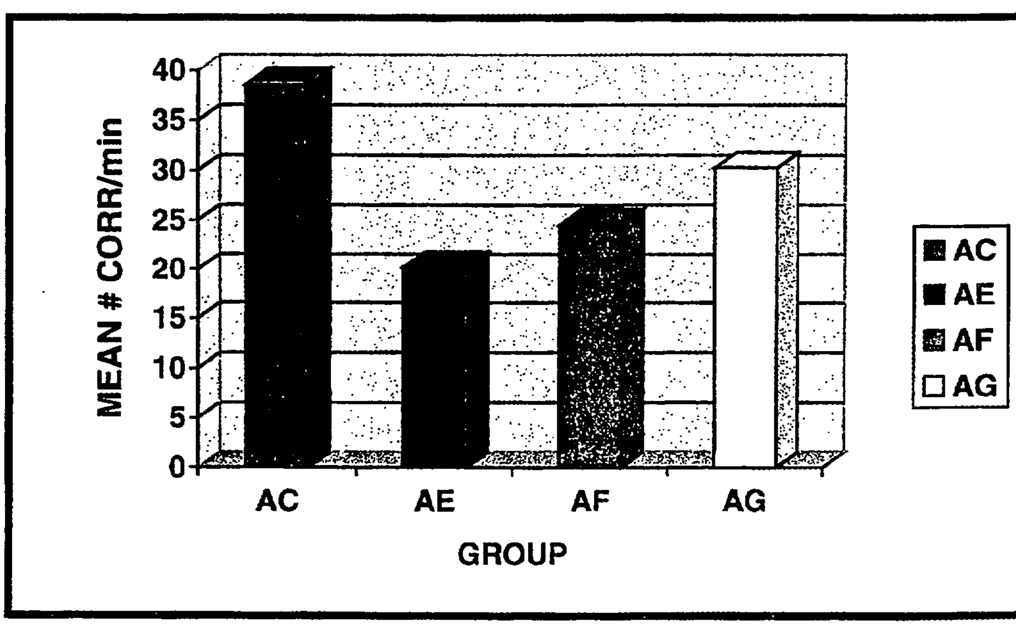

Figure 3-20. 4-year averaged performances on ANAMUKR: MSP-EFF.

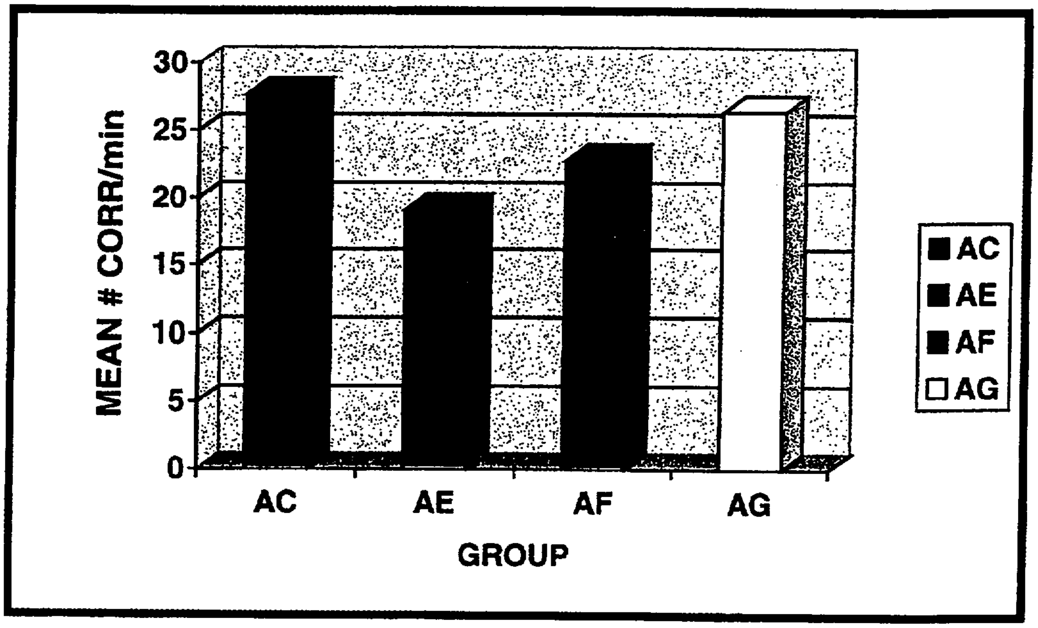

Figure 3-21. 4-year averaged performances on ANAMUKR: SPD-EFF.

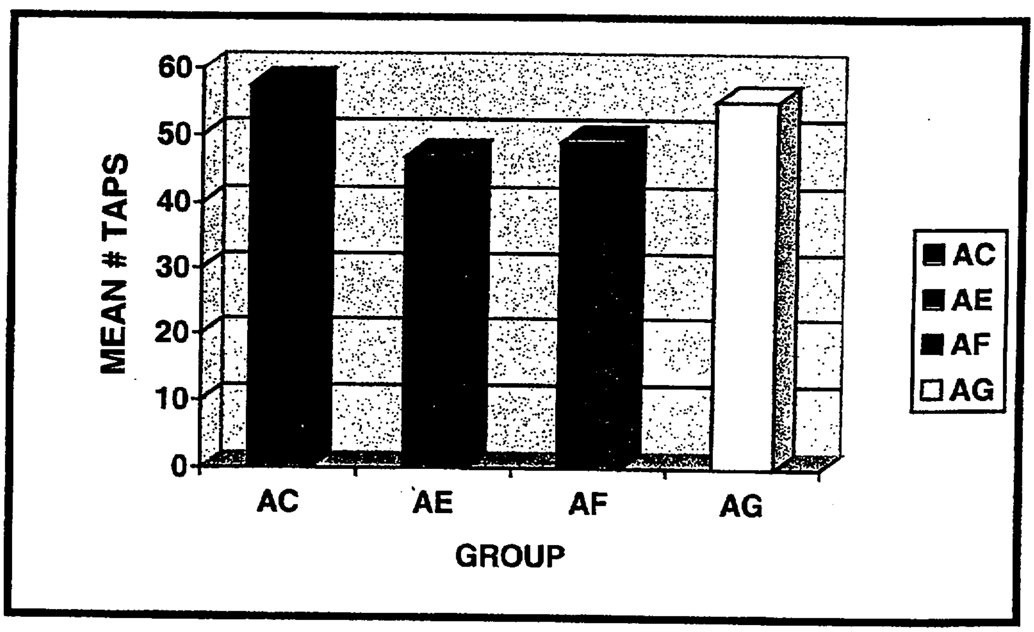

Figure 3-22. 4-year averaged performances on ANAMUKR: TAPPING-RIGHT.

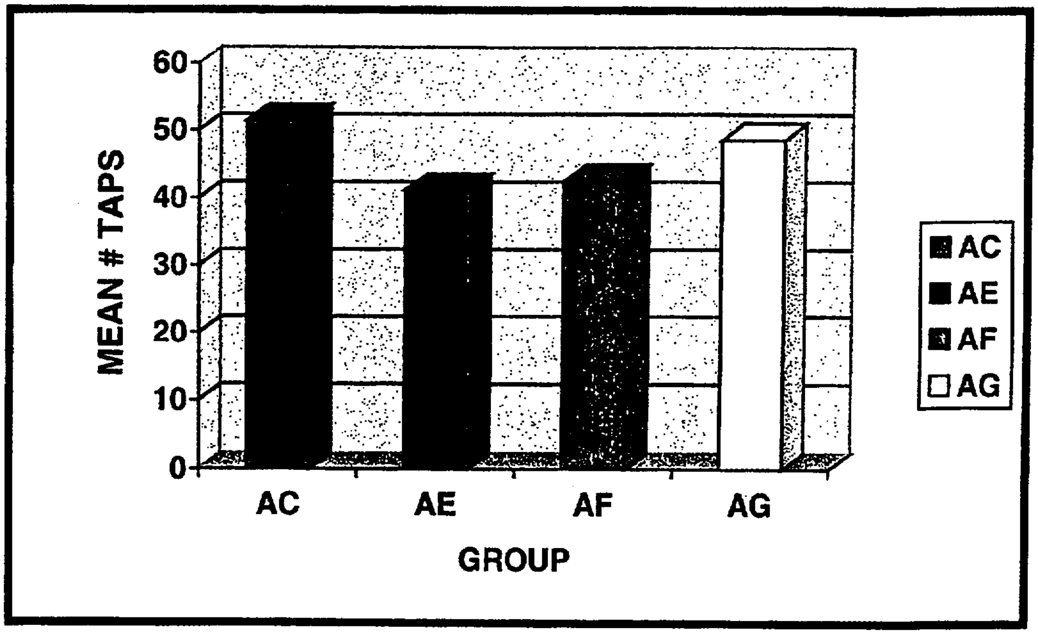

Figure 3-23. 4-year averaged performance on ANAMUKR: TAPPING LEFT.

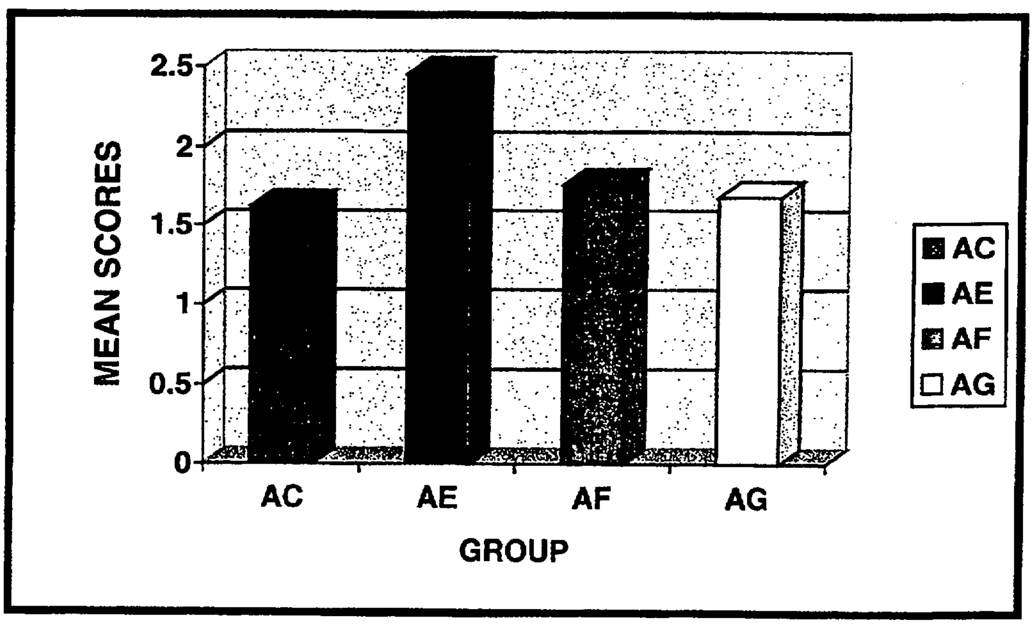

Figure 3-24. 4-year averaged scores on ANAMUKR: SLEEP SCALE.

3.3 RESULTS OF 1995 INITIAL TEST SESSION.

Because performance on the tasks within and among the test batteries is indexed in a variety of different ways, a measure was required which would describe comparisons between the exposure groups and the control group in similar terms across the tasks and test batteries. This measure consisted of determining the proportion of the control group's mean on a given task equivalent to an exposure group's mean on that task (i.e. mean-E / mean-C). The complement of this proportion (1-prop.) reflects the proportional difference between the means of the two groups on the task, and when multiplied by 100 it reflects the percent difference between the means of the two groups. The mean % difference for a given test battery was then calculated by obtaining the mean of the % differences for all the tasks in that battery. In all four cases the mean of a given exposure group on any given task was either equal to, or (most typically) less, than that of the control group. Therefore, the mean differences of all exposure groups on all test batteries reflected decrements in performance, as compared to the control group. Thus it seemed appropriate to describe the composite results of the 1995 test session in terms of mean % decrements as shown by the exposure groups relative to the control group, on all test batteries. These are presented in Table 3-6 and graphically in Figure 3-25.

Table 3-6. Mean % performance decrement for exposure groups relative to controls-1995.

GROUP	GPAB	ANAMUKR-ACC	ANAMUKR-EFF
AE	27.00	11.00	40.52
AF	16.88	7.35	23.91
AG	12.49	3.09	22.51

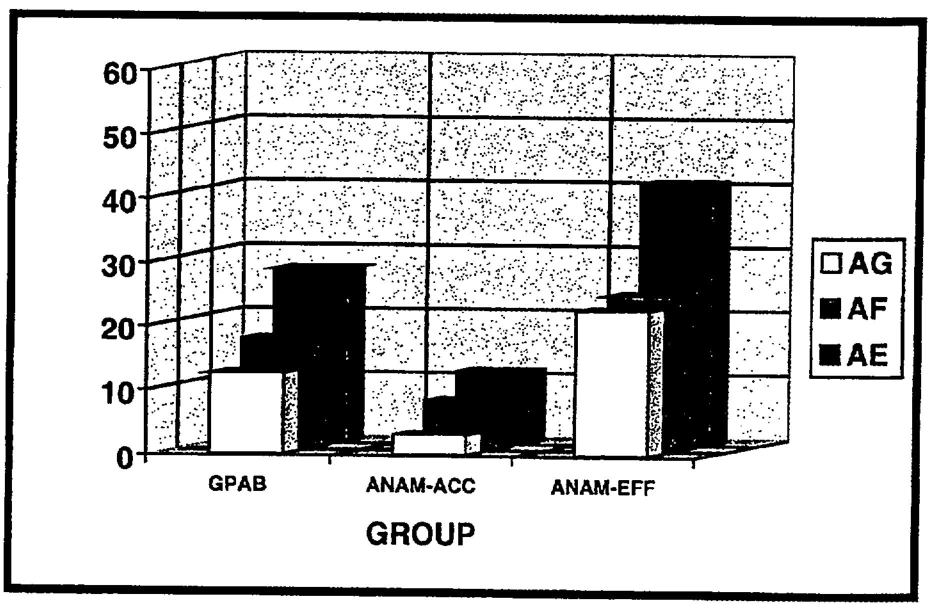

Figure 3-25. Mean % Decrement for Exposure Groups Relative to Controls-1995.

All of these decrements were significant, as evidenced by the results of multivariate analyses of variance (MANOVAs) described later. As dramatically illustrated in Figure 3- 25, the Eliminators were most drastically affected by their exposure to the radiation in the power station, on all test batteries. The other groups were also affected (although to a lesser degree) by the radiation in the Chernobyl region and showed sizeable decrements in performance on the test batteries as well.

3.3.1 GPAB.

Means and standard deviations for the groups on the GPAB are presented in Table 3-7.

Table 3-7. GPAB: 1995 Means (and standard deviations) for the four groups.

GROUP→ TASK	*AC*	*AE*	*AF*	*AG*
BROADJMP (meter)	1.57 (.18)	1.40 (.17)	1.39 (.16)	1.43 (.45)
CARRYWGT (meter)	43.42 (3.85)	36.61 (7.24)	37.17 (6.09)	40.58 (5.57)
SQUATTHR (number)	62.65 (10.01)	22.42 (8.78)	35.52 (12.72)	44.10 (17.39)
BALBEAM (meter)	19.61 (1.19)	16.22 (2.30)	19.93 (1.51)	18.65 (2.22)

The results of a MANOVA (Table 3-28) revealed a significant difference on the composite MEASURES. Univariate ANOVAs and *post-hoc* Dunnett tests, the results of which are presented in Tables 3-8 and 3-9, indicated that the ***AE***s were significantly impaired on *all 4* tasks as compared to the *AC*s. The ***AF***s were significantly lower than the *AC*s on **BROADJMP**, **CARRYWGT** and **SQUATTHR**, while the *AG*s were significantly lower on **SQUATTHR** only. Interestingly, the ***AF***s performed somewhat better than the *AC*s on **BALBEAM;** this may well have resulted from their training in forestry work, including balancing on logs.

Table 3-8. GPAB: Results of MANOVA and univariate ANOVAS.

TASK	F	p<
COMP*	21.10	.001
BROADJMP	2.92	.05
CARRYWGT	9.33	.001
SQUATTHR	59.65	.001
BALBEAM	26.53	.001

Note: *Wilks' Lambda = .21

Table 3-9. GPAB: Groups significantly lower on physical abilities tasks than *AC*.

TASK	GROUP	p<
BRODJMP	*AE, AF*	.05, .05
CARRYWGT	*AE, AF*	.001, .001
SQUATTHR	*AE, AF, AG*	.001, .001, .001
BALBEAM	*AE*	.001

A discriminant function analysis, the results of which are presented in Table 3-10, indicated that the GPAB is extremely sensitive to the effects of exposure to ionizing radiation: 98.51% of ***AC***s and ***AE***s were correctly classified. Table 3-10 represents numbers of subjects.

Correlational analyses were performed for dosage of radiation and measures of physical performance for the ***AE***s. Significant negative correlations of rads with performance on **BRODJMP** and **SQUATTHR** (both ***rs***>-.35, ***ps***<.05) were revealed.

Table 3-10. GPAB: Results of discriminant function analysis for groups *AC* and *AE*.

ACTUAL GROUP	PREDICTED GROUP--*AC*	PREDICTED GROUP--*AE*
AC **(number)**	31	0
AE **(number)**	1	35

Subsequent analyses included comparisons of performance scores of females and males as a function of non-exposure or exposure to radiation. The control group included only 7 females; thus 7 males from this group were selected for comparison purposes. The 3 exposed groups included a total of 17 females, so 17 males (matching the numbers of females from each of these groups) were selected. Selection of males was not altogether random, since an attempt was made to ensure equivalence of ages between females and males. Means and standard deviations for the groups resulting from the combination of these variables are presented in Table 3-11, for each of the 4 physical tasks. The results of a MANOVA and univariate tests are presented in Table 3-12. MANOVA creates a composite measures based upon the corrolation relationship between individual measures.

Significant differences on the composite measures were revealed for the main effects of gender and exposure; however, the multivariate interaction was not significant. The univariate tests indicated that overall, males performed significantly better than females on **BRODJMP, CARRYWGT** and **SQUATTHR**, but not on **BALBEAM**. Further, the controls were significantly better than the exposed people on **SQUATTHR** and **BALBEAM**. None of the univariate interactions were significant, however, indicating that the magnitudes of the female-male differences did not differ as a function of exposure to radiation.

Table 3-11. GPAB: Means (and standard deviations) for females and males, either not exposed (controls) or exposed to radiation.

TASK	FEMALES-CONTROL	FEMALES-EXPOSED	MALES-CONTROL	MALES-EXPOSED
BROADJMP (meter)	1.36 (.11)	1.24 (.31)	1.72 (.13)	1.58 .37)
CARRYWGT (meter)	38.14 (2.04)	33.88 (6.38)	44.71 (3.25)	39.88 (7.27)
SQUATTHR (number)	46.86 (5.49)	36.41 (15.12)	66.29 (4.19)	44.82 (22.55)
BALBEAM (meter)	19.21 (.91)	17.19 (1.91)	20.21 (1.43)	18.44 (2.79)

Table 3-12. GPAB: MANOVA and univariate tests for females and males, either exposed or not exposed (controls) to radiation.

SOURCE	TASK	*F*	*p*<
FEMALE-MALE	COMP*	4.28	.01
	BRODJMP	13.42	.001
	CARRYWGT	5.05	.05
	SQUATTHR	7.00	.01
	BALBEAM	2.76	
CONTROL-EXPOSED	COMP**	3.34	.05
	BRODJMP	1.59	
	CARRYWGT	1.78	
	SQUATTHR	9.19	.01
	BALBEAM	7.85	.01
INTERACTION	COMP***	1.25	
	BRODJMP	.002	
	CARRYWGT	1.44	
	SQUATTHR	1.10	
	BALBEAM	.03	

Notes: * Wilks' Lambda = .71
** Wilks' Lambda = .75
*** Wilks' Lambda = .89

3.3.2 ANAMUKR: Accuracy.

Means and standard deviations of accuracy scores for the 9 ANAM tasks are presented in Table 3-13. Since all scores on **SRT** were 100%, this task was not included in data analyses. The results of a MANOVA revealed a significant difference on the composite measures. Univariate ANOVAs and *post-hoc* Dunnett tests indicated that these results were primarily due to the ***AE***s being significantly less accurate than the ***AC***s on 6 of the tasks: **CDS, CDI, CDD, CPT, DGS,** and **MSP.** These data indicate that the ***AE***s are experiencing remarkable decrements in short-term (working) memory, as 5 of these tasks assess integrity of this cognitive skill. The ***AF***s performed less accurately than the ***AC***s on 5 tasks: **2CH, CDI, CDD, DGS,** and **MSP.** Apparently, they are also experiencing some difficulties in short-term memory.

The ***AG***s were significantly less accurate on 2 tasks: **DGS** and **MSP.** Thus all the exposed groups are being affected by the ionizing radiation in varying degrees, as compared to the control group. The results of these analyses are presented in Tables 3-14 and 3-15.

Table 3-13. Accuracy (% Correct): 1995 Means (and Standard Deviations).

GROUP→ TASK	*AC*	*AE*	*AF*	*AG*
SRT	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)	100.00 (0.00)
2CH	97.52 (3.51)	96.94 (3.19)	94.10 (7.05)	96.97 (2.83)
CDS	97.74 (1.84)	95.39 (3.77)	95.97 (3.55)	96.35 (3.05)
CDI	97.84 (4.10)	83.69 (15.48)	87.90 (8.33)	93.32 (6.67)
CDD	97.10 (3.42)	84.00 (16.84)	88.14 (9.23)	93.00 (7.75)
CPT	96.19 (4.29)	76.28 (15.72)	90.55 (8.28)	91.74 (5.56)
DGS	89.84 (8.52)	73.69 (13.46)	82.03 (11.28)	83.13 (7.96)
MSP	98.42 (2.98)	84.83 (10.64)	82.03 (11.28)	89.71 (15.18)
SPD	90.16 (5.24)	87.08 (8.97)	87.76 (8.41)	96.97 (2.83)

Table 3-14. Accuracy: Results of MANOVA and Univariate ANOVAs.

TASK	F	$p<$
COMP*	7.81	.001
2CH	3.67	.01
CDS	3.25	.05
CDI	12.74	.001
CDD	9.14	.001
CPT	26.03	.001
DGS	12.98	.001
MSP	13.35	.001
SPD	13.55	.001

Note: *Wilks' Lambda = .28

Table 3-15. Accuracy: Groups significantly less accurate than *AC*.

TASK	GROUP	$p<$
2CH	*AF*	.01
CDS	*AE*	.01
CDI	*AE, AF*	.001, .001
CDD	*AE, AF*	.001, .01
CPT	*AE*	.001
DGS	*AE, AF, AG*	.001, .05, .05
MSP	*AE, AF, AG*	.001, .001, .01
SPD	NONE	

The results of a discriminant function analysis for the *AC*s and *AE*s are presented in Table 3-16. The high percentage of correct classification (93%) is mainly a result of all the *AC*s being correctly classified, as only 14% of the *AE*s were misclassified. Nonetheless, accuracy of performance would appear to be a good indicator of the effects of the hazardous environment surrounding Chernobyl, and it is as sensitive to these effects as to those resulting from traumatic brain injury (Levinson & Reeves, 1997) and stroke (Goldstone et al. 1995).

Levels of exposure to varying dosages of radiation were obtained for each of the *AE*s. Mean dose was 62.95 (SD=32.64); these ranged from 18 rads to 144 rads. No significant correlations between rads dose and accuracy on any of the tasks were found.

Table 3-16. Accuracy: Results of discriminant function analysis for groups *AC* and *AE*.

ACTUAL GROUP	PREDICTED GROUP--*AC*	PREDICTED GROUP--*AE*
***AC* (numbers)**	31	0
***AE* (numbers)**	5	31

3.3.3 ANAMUKR: Efficiency.

Means and standard deviations of efficiency scores for the 9 ANAM tasks are presented in Table 3-17. Scores on **SRT** were included in these analyses. Once again, the results of a MANOVA (Table 38) revealed a significant difference on the composite measures. Univariate ANOVAs and ***post -hoc*** Dunnett tests, the results of which are presented in Tables 3-18 and 3-19, indicated that the ***AE***s were significantly impaired on ***all 9*** tasks as compared to the ***AC***s. These effects appear to be extremely profound: the mean response time on **SRT** was greater than that of a group of 70-year olds (Goldstone, et al. 1995); in fact, a discriminant function analysis, the results of which are presented in Table 3-20, resulted in over 91% correct classification of the ***AC***s and ***AE***s, with 34 of the 36 ***AE***s being correctly classified. The global impairment seen here is reminiscent of that observed in individuals who have suffered moderate traumatic brain injury (Levinson & Reeves, 1997). As with accuracy, the effects were not limited to the ***AE***s. The ***AF***s were significantly less efficient than the ***AC***s on 7 tasks: **SRT, CDS, CDI, CDD, CPT, DGS,** and **MSP**. The efficiency of the ***AG***s was similarly affected; they were significantly less efficient than the ***AC***s on 6 tasks: **CDS, CDI, CDD, CPT, DGS,** and **MSP**.

Since efficiency is partially based upon response speed, and since it was significantly lower for the ***AE***s on all tasks (and for the ***AF***s and ***AG***s on most of them), a MANCOVA was performed in which **SRT** was entered as a covariate. It was believed that adjusting for differences on this primarily motor measure would yield a clearer assessment of CNS-processing of information. Although a multiple regression analysis indicated that **SRT** was significantly correlated with the other measures combined (Multiple **R**=.72, ***p***<.0001), the effect of adjusting for differences in **SRT** was slight (e.g., Wilks' Lambda increased from .28 to .33), and the overall picture emerging from the original MANOVA was not appreciably altered (see Table 3-18). These findings would appear to indicate that the observed differences in cognitive performance are reflective of impairments in information processing due to factors other than simple response speed.

Table 3-17. Efficiency (Correct responses/min): 1995 means (and standard deviations).

GROUP→ TASK	*AC*	*AE*	*AF*	*AG*
SRT	167.26 (46.34)	117.78 (43.14)	131.76 (47.05)	147.71 (48.24)
2CH	110.87 (25.49)	86.94 (27.06)	98.62 (32.97)	116.42 (19.63)
CDS	49.42 (14.44)	28.64 (8.74)	31.52 (18.69)	38.58 (13.95)
CDI	49.77 (15.39)	21.72 (8.44)	30.55 (17.67)	32.64 (12.13)
CDD	52.61 (13.04)	27.89 (10.94)	35.69 (19.85)	38.29 (10.81)
CPT	96.74 (19.68)	58.86 (16.88)	82.90 (22.63)	81.35 (18.53)
DGS	44.65 (10.45)	26.17 (8.07)	35.14 (10.11)	29.94 (8.06)
MSP	51.55 (16.77)	26.39 (10.49)	32.59 (19.14)	29.29 (11.20)
SPD	32.61 (9.85)	20.33 (6.05)	32.14 (11.88)	26.03 (7.27)

Table 3-18. Efficiency: Results of MANOVA and univariate ANOVAs (and MANCOVA and univariate ANCOVAs with SRT as a covariate).

TASK	F	p<
COMP*	6.79 (6.51)	.001 (.001)
SRT	7.00	.001
2CH	8.15 (4.58)	.001 (.01)
CDS	13.77 (6.55)	.001 (.001)
CDI	24.27 (16.14)	.001 (.001)
CDD	17.98 (11.29)	.001 (.001)
CPT	22.14 (14.77)	.001 (.001)
DGS	24.75 (18.46)	.001 (.001)
MSP	19.20 (13.55)	.001 (.001)
SPD	14.11 (11.42)	.001 (.001)

Notes: *Wilks' Lambda = .28 (.33)

Table 3-19. Efficiency: Groups significantly less efficient than *AC*.

TASK	GROUP	p<
SRT	*AE, AF*	.001, .01
2CH	*AE*	.001
CDS	*AE, AF, AG*	.001, .001, .01
CDI	*AE, AF, AG*	.001, .001, .001
CDD	*AE, AF, AG*	.001, .001, .001
CPT	*AE, AF, AG*	.001, .01, .01
DGS	*AE, AF, AG*	.001, .001, .001
MSP	*AE, AF, AG*	.001, .001, .001
SPD	*AE, AG*	.001, .01

Table 3-20. Efficiency: Results of discriminate function analysis for groups *AC* and *AE*.

ACTUAL GROUP	PREDICTED GROUP--*AC*	PREDICTED GROUP--*AE*
AC (numbers)	27	4
AE (numbers)	2	34

Correlational analyses were also performed for dose of radiation and efficiency of performance for the *AE*s. Unlike accuracy, significant negative correlations of rads dose with efficiency on **CDI**, **CDS**, **CPT**, **DGS**, and **MSP** (all of which assess short-term memory), as well as with **SRT** (all $rs>-.36$, all $ps<.05$) were revealed.

3.3.4 ANAMUKR*:* Additional Measures.

Means and standard deviations for the groups on **TAPR**, **TAPL**, and **SLP** are shown in Table 3-21.

Table 3-21. ANAMUKR additional measures: Means (and standard deviations).

GROUP → TASK	*AC*	*AE*	*AF*	*AG*
TAP-R (mean n of responses in 10 sec.)	54.26 (11.48)	41.31 (14.37)*	45.90 (13.05)*	49.87 (12.27)
TAP-L (mean n of responses in 10 sec.)	47.44 (9.85)	37.26 (12.15)*	40.30 (11.93)*	46.97 (9.33)
SLP (scores from 1-7)	1.84 (1.29)	2.88 (1.45)*	2.29 (.70)	2.63 (1.17)

Note: *significantly different than controls

Differences among the groups were significant on all of these measures ($Fs > 4.36, ps < .01$). Compared to the *AC*s, tapping rates for both hands were significantly lower for the *AE*s (.001) and for the *AF*s (.05); while levels of sleepiness were higher for the *AE*s (.001).

3.3.5 GPAB-ANAMUKR*:* Correlational Analyses.

Significant correlations were found between many of the measures on the GPAB; these are presented in Table 3-22, along with intercorrelations between performance on the tasks comprising the GPAB and accuracy of performance on the tasks in ANAMUKR for the combined groups (N=127).

Table 3-22. Pearson correlations between GPAB and ANAMUKR: Accuracy (N=127).

TASK	BRODJMP	CARRY WGT	SQUATTHR	BALBEAM
BRODJMP				
CARRYWGT	.59**			
SQUATTHR	.62**	.65**		
BALBEAM	-.04	.14	.30**	
CDD	.01	.11	.27**	.19*
CDI	.14	.32**	.37**	.17
CDS	.02	.06	.11	.21*
CPT	.18	.21*	.48**	.45**
DGS	.15	.14	.37**	.26**
MSP	.29**	.31**	.41**	.05
SPD	-.06	.11	.08	.14
SRT	.03	-.08	.06	.09
2CH	-.07	-.02	-.05	- .01

Notes: * $p<.05$
** $p<.01$

As indicated above, **SQUATTHR** was significantly and positively correlated with all other physical tasks, and with accuracy of performance on cognitive tasks involving working memory. Further, **BALBEAM** was significantly and positively correlated with accuracy on **CPT**; both of these tasks require sustained attention.

Similar Pearson correlations were calculated for each separate group. Because of the reductions in sample size, many of the significant correlations observed for the combined groups were lost. Nonetheless, a few interesting ones remained. For the *AC*s, **CARRYWGT** and **SQUATTHR** were correlated with **CDS** and **CDI**; while for the *AE*s and *AG*s, **BALBEAM** was correlated with **CPT**.

The intercorrelations between performance on the tasks in the GPAB and efficiency of performance on the tasks in ANAMUKR are presented in Table 3-23. Compared to accuracy, many more significant correlations were observed between ANAMUKR efficiency and physical performance. Especially noteworthy is the finding that **SQUATTHR** was significantly and positively correlated with *all* cognitive tasks. In addition **BALBEAM** was significantly and positively correlated with many of the cognitive tasks requiring sustained attention and working memory (e.g., **CPT**, **CDI**, and **CDD**).

As was the case with the correlations between cognitive accuracy and physical performance, much of the significance of the correlations between cognitive efficiency and physical performance was lost when they were calculated for the individual groups. However, several interesting significant correlations remained, including **BALBEAM-CPT** for the *AE*s, and **SQUATTHR** and several tasks for the *AG*s.

Table 3-23. Pearson correlations between GPAB and ANAMUKR: Efficiency (N=127).

TASK	BRODJMP	CARRYWGT	SQUATTHR	BALBEAM
CDD	.04	.07	.42**	.26**
CDI	.21*	.20*	.54**	.24**
CDS	.23*	.19*	.45**	.16
CPT	.28**	.19*	.49**	.40**
DGS	.24**	.23**	.48**	.27**
MSP	.27**	.29**	.49**	.22*
SPD	.16	.15	.31**	.36**
SRT	.35**	.21*	.48**	.13
2CH	.10	.11	.24**	.23*

Notes: * $p < .05$
** $p < .01$

Table 3-24 presents the correlation between the GPAB tasks and the other ANAMUKR measures.

Table 3-24. Pearson correlations between GPAB and ANAMUKR: Additional measures (N=127).

TASK	BRODJMP	CARRYWGT	SQUATTHR	BALBEAM
TAP-R	.06	.13	.27**	.24**
TAP-L	.20*	.18*	.27**	.20**
SLP	- .24**	-.23*	-.37**	-.15

Notes: * $p < .05$
** $p < .01$

Since the tapping task measures fine motor coordination, it is not surprising that it is primarily correlated with **SQUATTHR** (a measure of dynamic strength) and **BALBEAM** (a measure of balance). Further, the correlations between tapping and balance may be reflective of cerebellar function. The finding that the ***AE*s** are significantly impaired on these tasks relative to the *AC*s might therefore indicate that the integrity of their cerebellar (as well as cerebral) function has been damaged by exposure to adionuclides. The negative correlations between **SLP** and the 3 **GPAB** tasks requiring strength would appear to at least indirectly support the validity of the sleep scale.

3.3.5.1 Age. Since ages of all 127 participants were obtained, correlations between it and all other variables were calculated. Significant negative correlations were observed between age and three of the GPAB tasks (**BRODJMP, CARRYWGT,** and **SQUATTHR**: all $rs > .36$, all $ps < .01$); in contrast, a significant positive correlation was revealed between age and **BALBEAM** ($r = .24$, $p < .01$). Significant negative correlations ($rs > .20$, $ps < .05$) were observed for accuracy on two ANAMUKR tasks (**CDI, MSP**), and for efficiency on five tasks (**CDS, CDI, CDD, MSP,** and **SRT**). Most of these are attention-memory tasks. These data are in concert with other studies relating age and cognitive performance (e.g., Goldstone, et. al, 1995).

3.4 RESULTS OF 1996 RETEST SESSION.

Two Eliminators and one Forestry worker were not available for the retest session, and therefore their 1995 data could not be included in the analyses of the retest results. The remaining Ns of the exposure groups were Eliminators-34, Forestry workers-28, and Agricultural workers-31. The Control group (AC) were tested in 1995, 1996, 1997 and 1998. There were no meaningful differences among these testings. It was decided to use the 1995 Control group as a comparison for all subsequent experimental groups.

3.5 GLOBAL ASSESSMENTS OF DECLINES BY EXPOSURE GROUPS.

Mean percent decrements in performance for the exposure groups on the 1996 retest relative to the 1995 Control data are presented in Table 3-25 and graphically illustrated in Figure 3-16.

Table 3-25. Mean % performance decrement for exp. groups-1996 relative to controls-1995.

GROUP	GPAB	ANAMUKR-ACC	ANAMUKR-EFF
AE	33.73	12.78	47.16
AF	16.38	10.11	35.42
AG	11.85	6.23	30.36

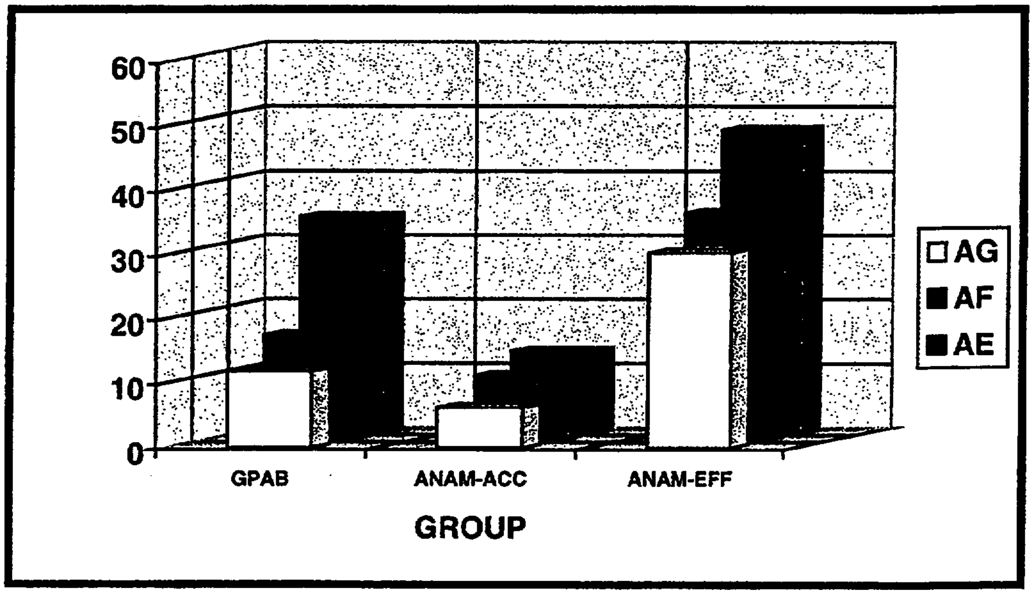

Figure 3-26. Mean % Decrement for Exposure Groups-1996 Relative to Controls-1995.

The data of Figure 3-26 are similar to those illustrated in Figure 3-25; however, except for Groups ***AF*** and ***AG*** on the GPAB, the magnitude of the 1996 differences between the exposure groups and the Controls is noticeably greater than those of 1995. In addition to declines in performance in groups significantly lower than the Controls in 1995, the performance of several groups not significantly lower than the Controls on certain tasks in 1995 declined to significant levels in 1996; these are listed in Table 3-46.

Using a procedure similar to that for calculating mean percent decrement of the exposure groups relative to the Controls, the mean percent declines for each of these groups on each battery of tests were calculated by using 1995 levels of performance as a baseline by which to gauge 1996 levels (i.e., mean - 1996 / mean-1995). These declines are presented in Table 3-27 and illustrated graphically in Figure 3-27. With the exception of Groups ***AF*** and ***AG*** on the GPAB, all groups showed significant declines as revealed by MANOVAs, the results of which are presented in Table 3-28, on all test batteries from 1995 to 1996. These findings indicate that both the physical (in the case of Group ***AE***) and cognitive performance levels in these groups of individuals are worsening over time.

Table 3-26. Groups not Significantly Lower than *AC* in 1995, but significantly lower in 1996.

BATTERY: TASK	GROUP	$p<$
GPAB		
BRODJUMP	*AE*	.001
ANAM-ACCURACY		
2CH	*AE, AG*	.01, .01
CDS	*AF*	.01
CDI	*AG*	.001
CDD	*AG*	.001
SPD	*AE, AF*	.001, .01
ANAM-EFFICIENCY		
SPD	*AF*	.001

Table 3-27. Mean % Performance Decline for Exposure Groups: 1995-1996.

GROUP	GPAB	ANAMUKR-ACC	ANAMUKR-EFF
AE	9.78	1.95	11.89
AF	0.00	2.84	15.22
AG	0.00	3.18	9.03

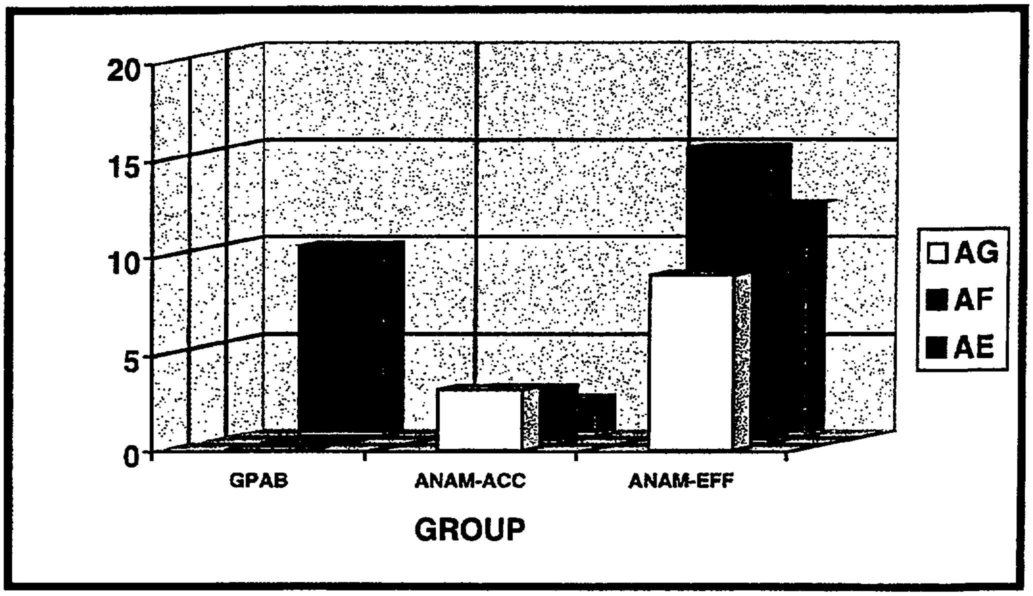

Figure 3-27. Mean % decline for exposure groups: 1995-1996.

Table 3-28. Significant multivariate declines by exposure groups.

TEST BATTERY	GROUP	WILKS' LAMBDA	F	*p*<
GPAB	*AE*	.39	11.95	.001
ANAM-ACC	*AE* *AF* *AG*	.51 .42 .38	3.07 3.49 4.60	.01 .01 .01
ANAM-EFF	*AE* *AF* *AG*	.39 .28 .32	4.39 5.01 5.32	.001 .001 .001

3.6 SPECIFIC ASSESSMENTS OF DECLINES IN EXPOSURE GROUPS.

Means and standard deviations for the exposure groups on the 1996 GPAB retest are presented in Table 3-29. Similar data for accuracy, efficiency, and the additional measures performance on the 1996 ANAMUKR retest are presented in Tables 3-30, through 3-32, respectively. Significant declines, as revealed by the results of univariate analyses comparing the 1996 levels of performance of the exposure groups on the various tasks in the test batteries to their 1995 levels, are presented in Table 3-33, along with the figure number from Figures 3-30 through 3-53 illustrating these declines.

3.6.1 GPAB.

Already significantly weaker than the *AC*s (1995), the *AE*s continued to decline on all measures of strength, including explosive, static and dynamic. These findings indicate that they are physically deteriorating, even 10 years following their exposure to the radiation in the power station. In contrast, the *AF*s and *AG*s maintained their 1995 levels--perhaps because they are working in occupations requiring physical exertion and were therefore able to "stay in shape".

TABLE 3-29. GPAB: 1996 means (and standard deviations) for the exposure groups.

TASK	*AE*	*AF*	*AG*
BRODJMP	1.30 (.28)	1.37 (.14)	1.41 (.42)
CARRYWGT	30.56 (11.68)	38.89 (5.93)	41.48 (6.03)
SQUATTHR	19.47 (7.44)	35.39 (11.97)	43.74 (17.07)
BALBEAM	15.85 (3.16)	20.02 (1.76)	19.11 (1.20)

3.6.2 ANAMUKR: Accuracy.

All three exposure groups showed significant declines in accuracy of performance on a variety of the tasks. Most of these declines occurred in Groups *AF* and *AG*, on tasks assessing both attention and memory skills. Nonetheless, the *AE*s declined as well, on tasks requiring sustained attention. Surprisingly, all three groups showed significant declines on **SPD**, indicating a developing difficulty in skills related to assessment of spatial relations.

Table 3-30. ANAMUKR Accuracy (% correct): 1996 means (and standard deviations) for the exposure groups.

TASK	*AE*		*AF*		*AG*	
SRT	100.00	(.00)	100.00	(.00)	100.00	(.00)
2CH	94.26	(5.30)	94.79	(4.53)	93.90	(7.19)
CDS	93.59	(3.66)	94.07	(3.21)	95.39	(3.32)
CDI	79.85	(8.07)	82.96	(8.54)	88.71	(10.55)
CDD	79.53	(9.96)	81.11	(6.79)	84.00	(10.75)
CPT	83.24	(16.15)	89.11	(6.96)	91.61	(6.80)
DGS	74.82	(10.26)	83.43	(7.03)	85.16	(8.56)
MSP	80.94	(13.30)	81.18	(16.88)	89.58	(9.14)
SPD	80.88	(7.83)	81.79	(6.56)	88.55	(6.73)

3.6.3 ANAMUKR: Efficiency.

As with accuracy, all exposure groups exhibited significant declines in efficiency of performance on the majority of the tasks. Most of these were the same tasks upon which their accuracy declined. Thus the declines in efficiency are not surprising, since efficiency is based in part on accuracy of performance. Nonetheless, it should be noted that none of the groups showed significant declines in SRT, and therefore the declines in efficiency cannot be explained by slowing of response speed (the other factor upon which efficiency of performance is based). The finding that declines in efficiency for the most part accompanied corresponding declines in accuracy would indicate that these individuals are experiencing difficulty in processing cognitive information on tasks entailing attention, memory and spatial abilities.

Table 3-31. ANAMUKR Efficiency (correct responses/min): 1996 means (and standard deviations) for the exposure groups.

TASK	*AE*	*AF*	*AG*
SRT	117.74 (34.16)	136.93 (52.23)	139.00 (52.65)
2CH	76.47 (29.60)	90.39 (31.89)	98.13 (33.56)
CDS	23.35 (8.03)	31.79 (21.41)	30.45 (11.55)
CDI	17.35 (5.71)	27.57 (16.19)	26.29 (11.48)
CDD	20.74 (8.47)	25.50 (13.26)	29.13 (12.77)
CPT	61.26 (18.08)	74.14 (24.49)	79.74 (27.67)
DGS	25.26 (7.57)	29.39 (7.48)	30.87 (10.87)
MSP	19.82 (8.52)	21.82 (11.30)	31.81 (15.30)
SPD	18.41 (7.22)	21.18 (9.29)	24.97 (9.53)

3.6.4 ANAMUKR: Additional Measures.

Means and standard deviations for the exposure groups are shown in Table 3-32.

Table 3-32. ANAMUKR Additional measures: 1996 means (and standard deviations).

TASK	*AE*	*AF*	*AG*
TAP-R (mean n of responses in 10 sec)	42.82 (9.74)	48.351 (11.38)	55.58 (13.37)
TAP-L (mean n of responses in 10 sec)	37.97 (8.11)	41.00 (10.04)	49.30 (12.07)
SLP (scores from 1-7)	2.59 (.71)	1.27 (.46)	1.46 (.59)

No significant changes were observed from 1995 to 1996 in rates of tapping for either hand by any group; however, all 3 groups showed significant decreases in levels of sleepiness (all *F*s > 4.29, all *p*s < .05).

Table 3-33 shows the significant declines in performance from 1995 to 1996 for the GPAB tasks, and for accuracy and efficiency on ANAMUKR; the figure number refers to the figure which specifically illustrates the decline.

Table 3-33. Significant declines in performance by the exposure groups: 1995 to 1996.

BATTERY: TASK	GROUP	F	*p*<	FIG. #
GPAB				
BRODJUMP	***AE***	8.29	.01	30
CARRYING WGT	***AE***	31.58	.001	31
SQUATTHRUSTS	***AE***	16.32	.001	32
ANAM-ACCURACY				
2CH	***AE, AG***	7.90, 4.37	.01, .05	34
CDS	***AE, AF***	5.71, 7.90	.05, .01	35
CDI	***AF, AG***	5.52, 5.52	.05, .05	36
CDD	***AF, AG***	10.30, 12.53	.01, .001	37
SPD	***AE, AF, AG***	10.05, 12.04, 35.40	.01, .01, 001	41
ANAM-EFFICIENCY				
2CH	***AG***	7.45	.01	43
CDS	***AE, AG***	8.01, 10.96	.01, .01	44
CDI	***AE, AG***	6.15, 7.90	.01, .01	45
CDD	***AE, AF, AG***	11.02, 4.62, 10.89	.01, .05, .01	46
DGS	***AF***	7.51	.01	48
MSP	***AE, AF***	10.30, 8.01	.01, .01	49
SPD	***AF***	14.67	.001	50

3.7 RESULTS OF 1997 RETEST SESSION.

Because of unavailability for testing resulting from relocation, illness, or death, 1997 data were obtained on 34 Eliminators, 20 Forestry workers, and 28 Agricultural workers. However, some of these had not been available for testing on the GPAB and/or ANAMUKR in 1996, so the 1996-97 comparisons were based on Ns as follows: GPAB—Eliminators-32, Forestry workers-18, Agricultural workers-28; ANAMUKR—Eliminators-30, Forestry workers-15, Agricultural workers-28. Because many of the original forestry workers were unavailable for testing in 1997, a new group of 13 foresters was tested. However, since this was their first year of testing, their data could not be included in the analyses.

3.7.1 Global Assessments of Declines By Exposure Groups.

Mean percent decrements in performance for the exposure groups on the 1997 retest relative to the 1995 control data are presented in Table 3-34 and graphically illustrated in Figure 3-28. The data of Figure 3-28 are similar to those illustrated in Figures 3-25 and 3-26, except that decrements in ANAMUKR accuracy for Groups ***AE*** and ***AF*** are more pronounced.

Table 3-34. Mean % performance decrement for exp. groups-1997 relative to controls-1995.

GROUP	GPAB	ANAMUKR-ACC	ANAMUKR-EFF
AE	35.97	23.24	50.54
AF	9.93	14.96	43.68
AG	11.60	8.46	34.57

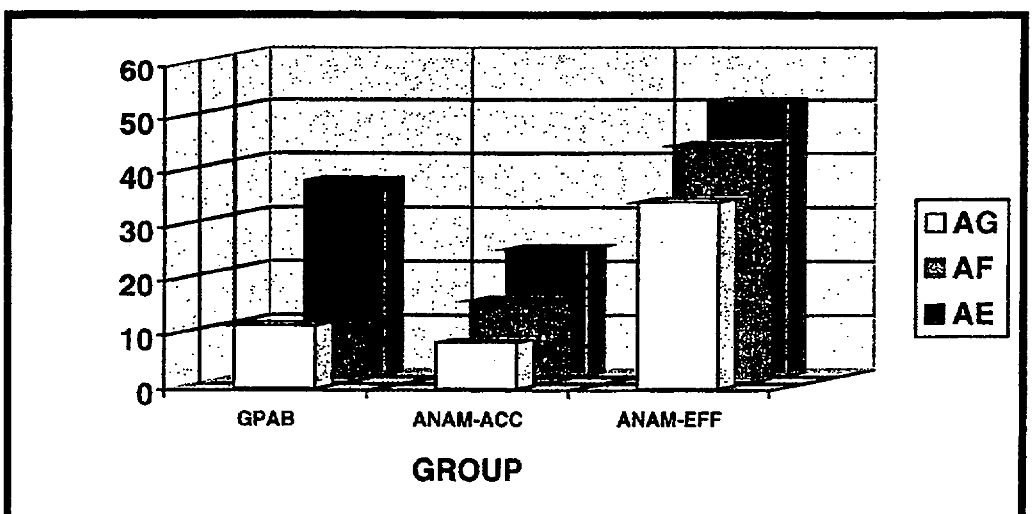

Figure 3-28. Mean % decrement for exposure groups-1997 relative to controls-1995.

In addition to continuing declines exhibited by all the groups on at least some of the measures, the performance of Groups ***AF*** and ***AG*** not significantly lower than that of the Controls in 1995 or 1996 declined to significant levels on several tasks in 1997. These are listed in Table 3-35.

Table 3-35. Groups not significantly lower than *AC* in 1995 or 1996, but significantly lower in 1997.

BATTERY: TASK	GROUP	$p<$
GPAB		
BALANCE BEAM	***AF***	.05
ANAM-ACCURACY		
CDS	***AG***	.05
CPT	***AF***	.001
ANAM-EFFICIENCY		
SRT	***AG***	.01
2CH	***AF, AG***	.001, .05

Using a procedure similar to that for calculating mean percent decrement of the exposure groups relative to the Controls, the mean percent declines for each of these groups on each battery of tests were calculated by using 1995 levels of performance as a baseline by which to gauge 1997 levels (i.e., mean - 1997 / mean-1995). These declines are presented in Table 3-36 and illustrated graphically in Figure 3-29. With the exception of Groups ***AF*** and ***AG*** on the GPAB, all groups showed significant declines as revealed by MANOVAs, the results of which are presented in Table 3-37, on all test batteries from 1995 to 1997. These findings indicate that both the physical (in the case of Group ***AE***) and cognitive performance levels in these groups of individuals are worsening over time.

Mean percent declines in performance by the 3 exposure groups from 1996 to 1997 are presented in Table 3-36 and graphically illustrated in Figure 3- 29. As revealed by MANOVAs, the decline of Group ***AE*** on the GPAB was significant, as were those of all 3 groups on ANAM accuracy. The declines in ANAM efficiency, although noteworthy, were not significant.

Table 3-36. Mean % performance decline for exposure groups: 1996-1997.

GROUP	GPAB	ANAMUKR-ACC	ANAMUKR-EFF
AE	3.00	12.43	5.20
AF	0.00	8.44	14.52
AG	0.00	2.43	6.41

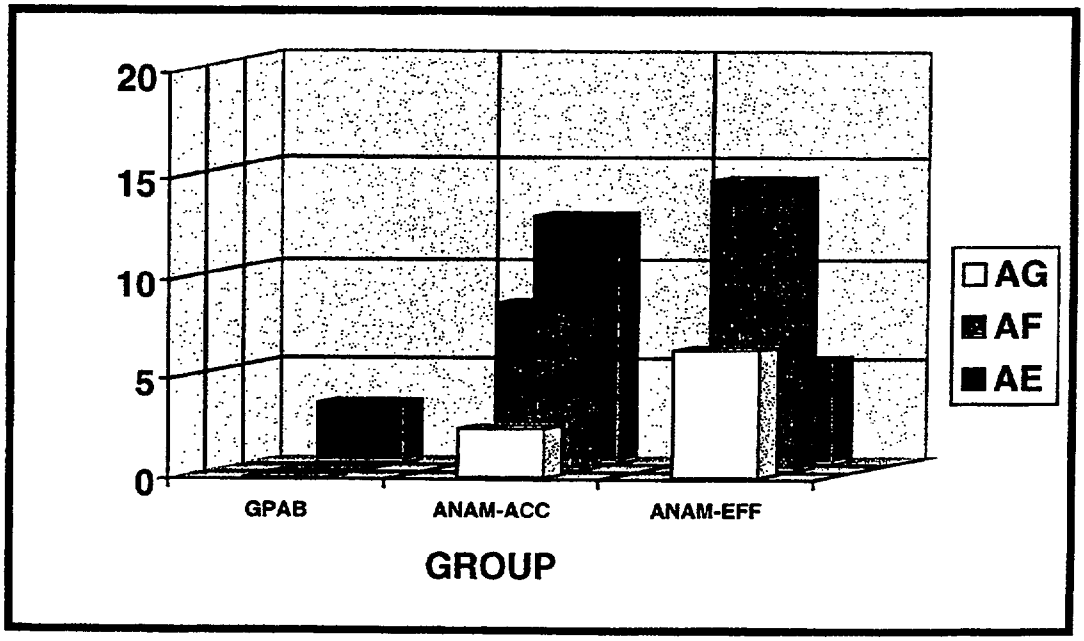

Figure 3-29. Mean % Decline for Exposure Groups: 1996-1997.

These findings indicate that the physical performance of Group ***AE*** and the accuracy of performance of all 3 exposed groups are continuing to significantly decline. Although a MANOVA indicated that the decline of Group ***AE*** on efficiency was also significant, a MANCOVA using **SRT** as a covariate revealed that the significance was a result of slowing of reaction time only (see Table 3-41). The results of the MANOVAs assessing the significance of the changes in performance for all 3 groups from 1996 to 1997 are presented in Table 3-37.

Table 3-37. Significant multivariate declines by exposure groups from 1996 to 1997.

TEST BATTERY	GROUP	WILK'S LAMBDA	F	*p*<
GPAB	*AE*	.52	6.48	.001
ANAM-ACC	*AE* *AF* *AG*	.14 .09 .47	17.31 8.62 2.84	.001 .01 .05
ANAM-EFF	*AE*	.39	3.63	.01*

Note: *n.s. when analyzed via MANCOVA using SRT as a covariate.

3.7.2 Specific Assessments of Declines in Exposure Groups.

Means and standard deviations for the exposure groups on the 1997 GPAB retest are presented in Table 3-38. Similar data for accuracy and efficiency of performance on the 1997 ANAMUKR retest, and for the additional ANAMUKR measures, are presented in Tables 3-39, through 3-41 respectively. Figures 3-30 through 3-53 illustrate changes in performance for the three exposure groups from 1996 to 1997 (as well as from 1995-1996). On each figure, the 1995 control data are again included as a point of reference. Significant declines, as revealed by the results of univariate analyses comparing the 1997 levels of the exposure groups on the various tasks in the test batteries to their 1996 levels, are presented in Table 3-42 along with the figure number from Figures 3-30 through 3-53 illustrating these declines.

Table 3-38. GPAB: 1997 means (and standard deviations) for the exposure groups.

TASK	*AE*		*AF*		*AG*	
BRODJMP (meter)	1.24	(.28)	1.42	(.20)	1.40	(.44)
CARRYWGT (meter)	28.32	(12.13)	42.05	(7.99)	41.00	(6.77)
SQUATTHR (number)	19.71	(8.39)	41.65	(13.81)	45.04	(19.30)
BALBEAM (meter)	15.76	(2.55)	20.95	(1.94)	19.25	(1.85)

Table 3-39. ANAMUKR: Accuracy (% correct): 1997 means (and standard deviations) for the exposure groups.

TASK	*AE*	*AF*	*AG*
SRT	100.00 (.00)	100.00 (.00)	100.00 (.00)
2CH	89.86 (6.91)	91.45 (12.00)	94.07 (16.82)
CDS	87.06 (8.50)	86.92 (9.18)	93.80 (3.91)
CDI	65.63 (14.29)	73.36 (11.19)	88.13 (8.74)
CDD	61.33 (10.82)	68.44 (11.91)	84.17 (9.39)
CPT	73.03 (14.13)	77.06 (10.84)	86.88 (12.91)
DGS	68.70 (11.67)	72.02 (10.66)	76.39 (12.35)
MSP	64.79 (17.04)	80.33 (11.34)	85.78 (13.75)
SPD	75.63 (10.22)	81.00 (9.12)	90.67 (8.48)

Table 3-40. ANAMUKR: Efficiency (correct responses/min): 1997 means (and standard deviations) for the exposure groups.

TASK	*AE*	*AF*	*AG*
SRT	94.69 (30.61)	103.23 (42.00)	133.87 (37.75)
2CH	67.28 (32.01)	75.70 (30.03)	91.45 (31.32)
CDS	23.89 (11.47)	20.03 (9.29)	30.44 (15.20)
CDI	19.28 (12.97)	21.26 (10.27)	27.19 (12.11)
CDD	18.55 (10.87)	25.00 (9.79)	27.13 (13.06)
CPT	54.01 (20.43)	58.27 (13.87)	71.16 (19.45)
DGS	23.00 (9.13)	26.12 (8.81)	25.80 (6.72)
MSP	18.43 (12.29)	24.09 (11.13)	27.04 (12.65)
SPD	20.66 (12.68)	20.16 (6.67)	24.63 (8.42)

Table 3-41. ANAMUKR: Additional measures: 1997 means (and standard deviations).

TASK	*AE*	*AF*	*AG*
TAP-R (mean n of responses in 10 sec)	42.97 (11.99)	51.20 (11.89)	57.47 (11.01)
TAP-L (mean n of responses in 10 sec)	37.81 (9.30)	46.16 (12.40)	51.43 (10.79)
SLP (scores from 1-7)	2.12 (.60)	1.87 (.64)	1.46 (.59)

3.7.3 GPAB.

From 1996 to 1997, Group ***AE*** declined on measures of explosive and dynamic strength, reflecting their continuing physical deterioration (see Table 3-42). Conversely, Groups ***AF*** and ***AG*** showed some improvement in physical abilities.

3.7.4 ANAMUKR: Accuracy.

As seen in Table 3-42, Group ***AE*** showed significant declines in accuracy from 1996 to 1997 on ***all*** tasks. This global decline in accuracy is most likely reflecting a general deterioration of their neurocognitive abilities; in fact, their levels of performance are similar to those observed in individuals with moderate-severe traumatic brain injuries (TBIs) (Levinson & Reeves, 1997; Levinson, et al, 1998). Similar declines were observed in Group ***AF***, on 6 of 8 tasks. Accuracy of performance of Group ***AG*** also declined on 3 tasks, although not as sharply as that of the other exposed groups.

3.7.5 ANAMUKR: Efficiency.

Group ***AE*** showed a significant decline in efficiency on **SRT** only, and when this was entered into a MANCOVA as a covariate, the multivariate difference in efficiency revealed by the MANOVA (see Table 3-37) was no longer significant. Group ***AF*** also showed a significant slowing of reaction time, and this most likely explains their corresponding decline in efficiency on **CPT**. Group ***AG*** did not exhibit any apparent slowing of reaction time, however, and therefore the significant declines on **CPT** and **DGS** are more likely reflecting difficulty in sustaining attention. At this point in time, the performance of all exposed groups on all tasks is significantly lower than that of the Controls.

Table 3-42. Significant declines in performance by the exposure groups: 1996 to 1997.

BATTERY: TASK	GROUP	F	p<	FIG. #
GPAB				
BROADJUMP	*AE*	7.87	.01	30
SQUATTHRUSTS	*AE*	3.49	.05*	32
ANAM-ACCURACY				
2CH	*AE*	14.59	.001	34
CDS	*AE, AF*	18.77, 11.88	.001, .001	35
CDI	*AE, AF*	23.02, 14.43	.001, .001	36
CDD	*AE, AF*	69.38, 14.21	.001, .001	37
CPT	*AE, AF, AG*	11.76, 18.07, 4.07	.001, .001, .05	38
DGS	*AE, AF, AG*	6.32, 16.09, 15.49	.01, .001, .001	39
MSP	*AE, AF, AG*	12.26, 9.29, 4.04	.001, .01, .05	40
SPD	*AE*	5.98	.05	41
ANAM-EFFICIENCY				
SRT	*AE, AF*	11.93, 7.24	.001, .01	42
CPT	*AF, AG*	5.56, 8.79	.05, .01	47
DGS	*AG*	13.89	.001	48

Note: *1-tailed

3.7.6 ANAMUKR*:* Additional Measures.

No significant declines in tapping rates for either hand were observed. Group *AE* showed a significant (.001) decrease in levels of sleepiness, while Group *AF* showed a significant increase.

3.8 RESULTS OF 1998 RETEST SESSION.

For similar reasons described for the 1997 retest, 1998 data were obtained on 22 Eliminators, 21 Forestry workers, and 29 Agricultural workers. Since some of these had not been available for testing on the GPAB and/or ANAMUKR in 1996, but were in 1997; therefore, the 1997-98 comparisons were based on Ns as follows: GPAB—Eliminators-22, Forestry workers-19, Agricultural workers-29; ANAMUKR—Eliminators-22, Forestry workers-20, Agricultural workers-29. Of the new group of 13 foresters from 1997, 8 were retested. Since this was only their second year of testing, their data were not included in the analyses.

3.8.1 Assessments of Declines by Exposure Groups.

Multivariate and univariate tests revealed no significant declines from 1997 levels on any measure in any of the test batteries, for any group. In fact, some of the groups showed significant increases in levels of performance compared to the 1995 control groups; these will be described in the relevant sections of this report.

3.8.2 GPAB.

Means and standard deviations on the 1998 retest are presented in Table 3-43. The ***AE***s showed significant increases in performance on **CARRYWGT, SQUATTHR** and **BALBEAM** (*ps* < .01), while the *AG*s improved on **CARRYWGT** (.05).

Table 3-43. GPAB: 1998 means (and standard deviations) for the exposure groups.

TASK	*AE*		*AF*		*AG*	
BRODJMP (meter)	1.29	(.16)	1.42	(.24)	1.51	(.40)
CARRYWGT (meter)	31.82	(12.40)	41.62	(8.56)	44.58	(6.98)
SQUATTHR (number)	23.91	(7.51)	40.52	(12.02)	51.35	(19.01)
BALBEAM (meter)	17.36	(1.59)	19.93	(1.88)	19.96	(2.81)

3.8.3 ANAMUKR: Accuracy.

Means and standard deviations for the 1998 accuracy retest are presented in Table 3-44. Although some improvements over the 1997 levels were observed in some groups, none of these was significant.

Table 3-44. ANAMUKR: Accuracy (% correct): 1998 means (and standard deviations for the Exposure Groups.

TASK	*AE*		*AF*		*AG*	
SRT	100.00	(.00)	100.00	(.00)	100.00	(.00)
2CH	89.90	(5.56)	88.89	(10.25)	92.86	(14.32)
CDS	89.70	(6.62)	88.20	(2.75)	94.99	(3.72)
CDI	63.83	(8.99)	74.06	(11.52)	85.29	(10.92)
CDD	64.20	(11.92)	72.19	(10.23)	79.53	(13.56)
CPT	73.07	(16.74)	82.29	(9.35)	87.96	(11.58)
DGS	68.75	(10.11)	72.29	(9.59)	76.01	(13.94)
MSP	67.57	(16.75)	79.63	(8.39)	85.63	(17.57)
SPD	82.05	(10.98)	83.25	(5.45)	91.72	(5.39)

3.8.4 ANAMUKR: Efficiency.

Means and standard deviations in efficiency are presented in Table 3-45 compared to the 1995 control group. Significant (.05) increases in efficiency of performance were made by the *AG*s on **SRT** and **SPD**. Although other increases in levels of performance were observed (see, e.g., Figures 3-43, 3-47, and 3-49), none were significant.

Table 3-45. ANAMUKR: Efficiency (correct responses/min) : 1998 means (and standard deviations) for the exposure groups.

TASK	*AE*	*AF*	*AG*
SRT	96.72 (38.46)	86.39 (20.87)	150.20 (31.82)
2CH	60.31 (30.64)	63.69 (22.84)	100.70 (26.94)
CDS	18.62 (7.61)	21.56 (13.28)	33.82 (11.59)
CDI	15.97 (9.63)	18.32 (13.11)	28.06 (12.38)
CDD	14.25 (6.10)	16.58 (8.19)	29.02 (10.22)
CPT	53.60 (16.77)	63.26 (13.80)	76.97 (15.54)
DGS	19.64 (5.66)	22.73 (8.38)	27.36 (7.04)
MSP	15.38 (9.89)	19.32 (13.10)	30.10 (13.31)
SPD	16.32 (9.07)	19.45 (9.27)	28.15 (6.85)

3.8.5 ANAMUKR: Additional measures.

Means and standard deviations for these are presented in Table 3-46. Group *AG* showed a significant increase (.05) in **TAP-L**.

Table 3-46. ANAMUKR: Additional Measures: 1998 Means (and Standard Deviations).

TASK	*AE*	*AF*	*AG*
TAP-R (mean n of responses in 10 sec)	47.64 (6.48)	49.65 (6.09)	59.48 (10.29)
TAP-L (mean n of responses in 10 sec)	40.80 (5.36)	43.53 (6.62)	53.84 (10.14)
SLP (scores from 1-7)	2.32 (.72)	1.70 (.66)	1.21 (.49)

Figures 3-30 through 3-53 graphically illustrate yearly changes in performance from 1995-1998 on all measures. The 4-year averaged levels of the Controls are represented as a straight dotted line (typically across the top) on each figure. Each graph represents the mean and the standard deviation are identified in their appropriate tables.

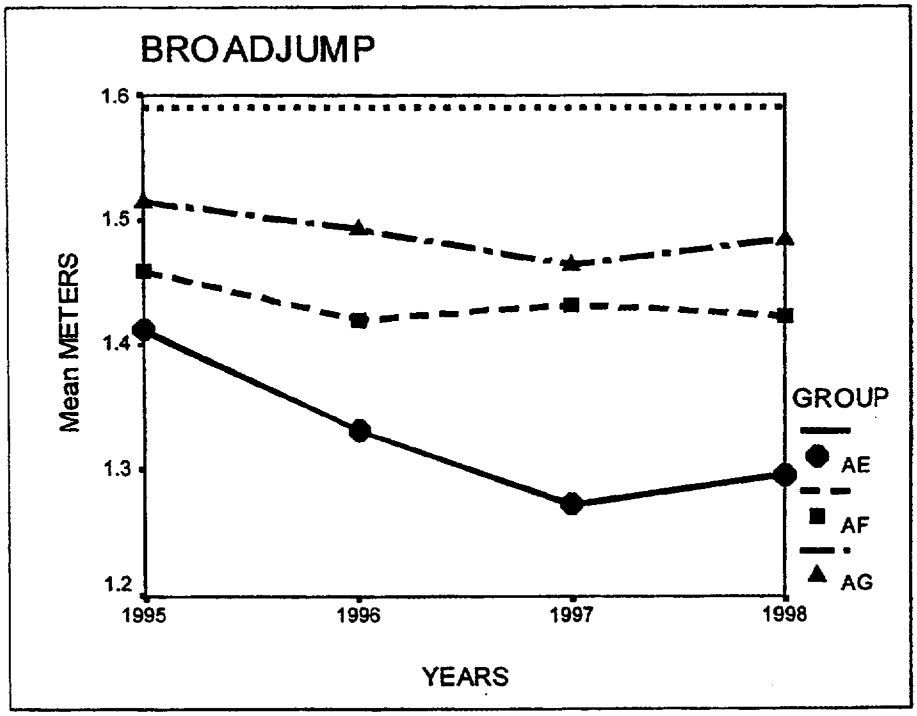

Figure 3-30. Mean performance on GPAB: BROADJUMP.

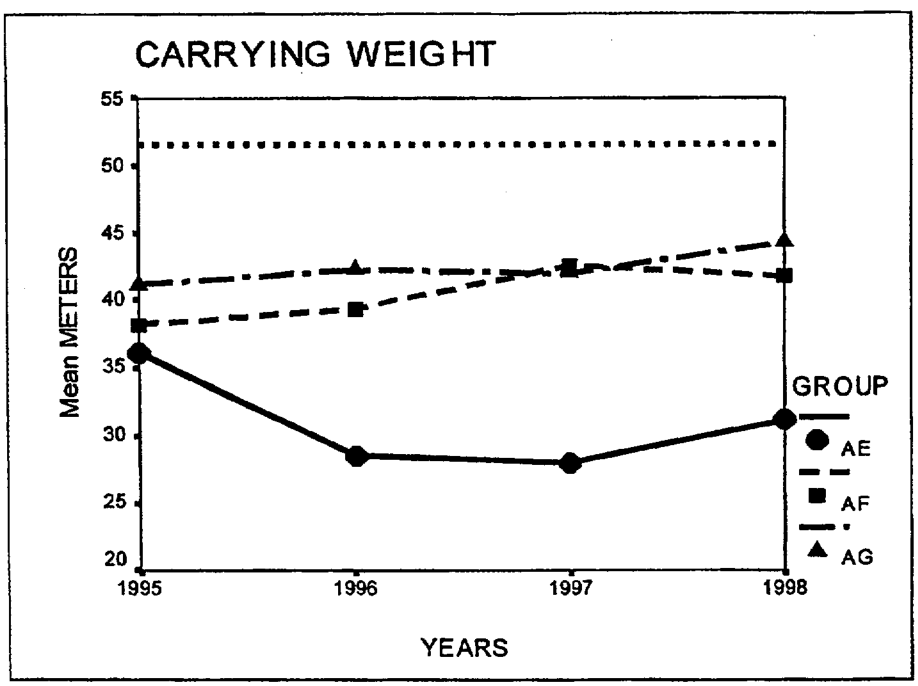

Figure 3-31. Mean performance on GPAB: CARRYING WEIGHT.

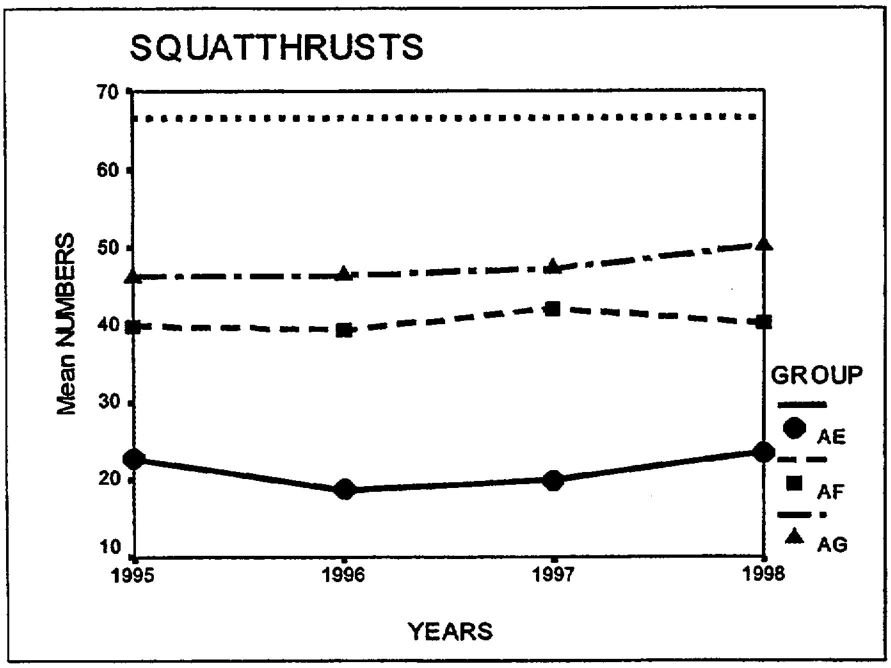

Figure 3-32. Mean performance on GPAB: SQUAT THRUSTS.

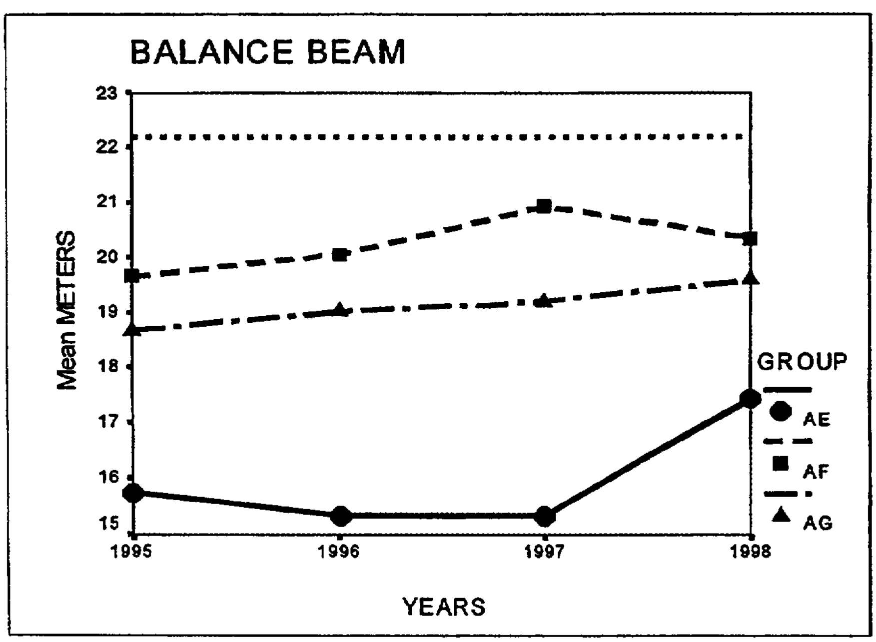

Figure 3-33. Mean performance on GPAB: BALANCE BEAM.

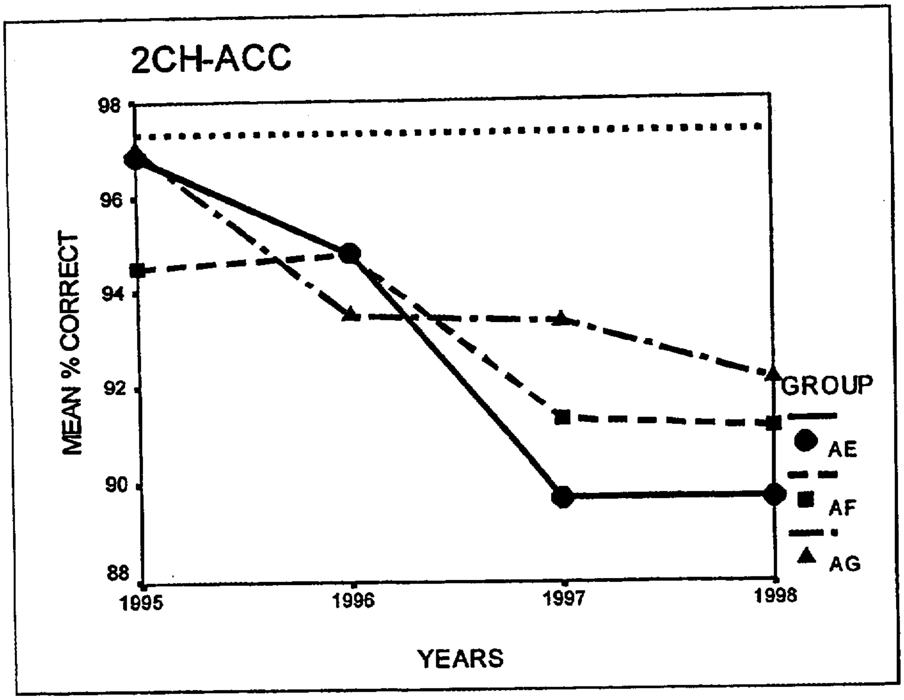

Figure 3-34. Mean performance on ANAMUKR: 2CH-ACC.

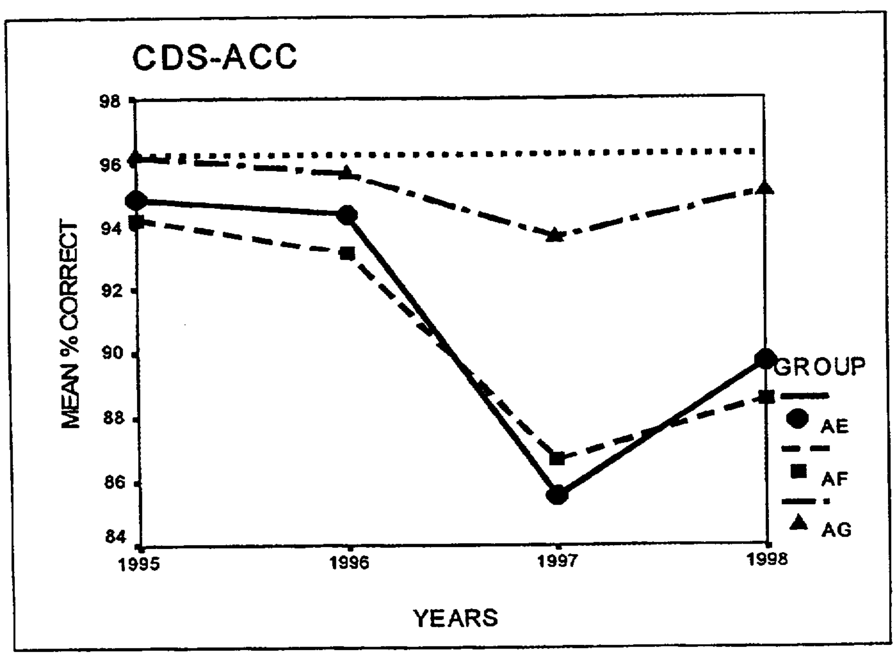

Figure 3-35. Mean performance on ANAMUKR: CDS-ACC.

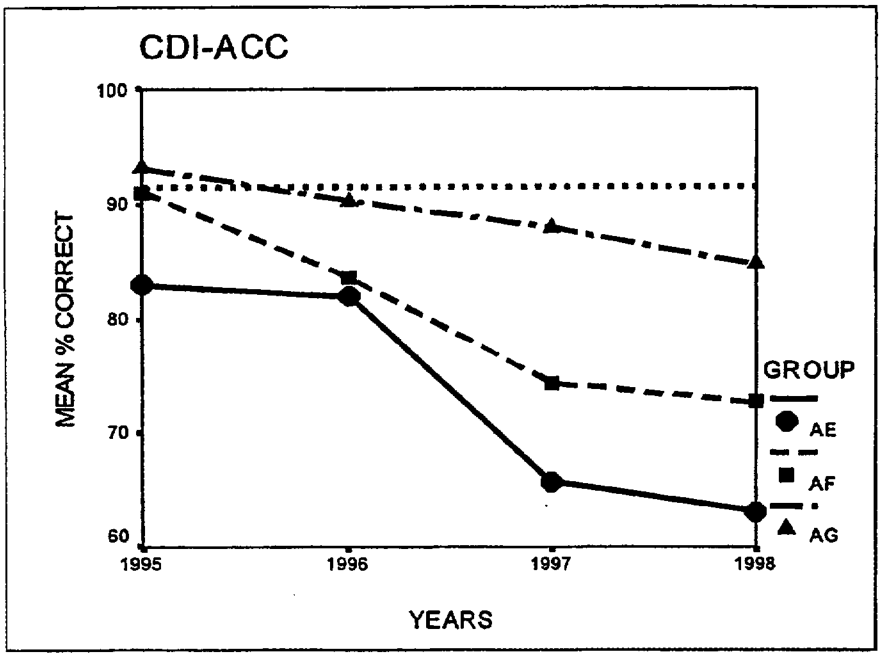

Figure 3-36. Mean performance on ANAMUKR: CDI-ACC.

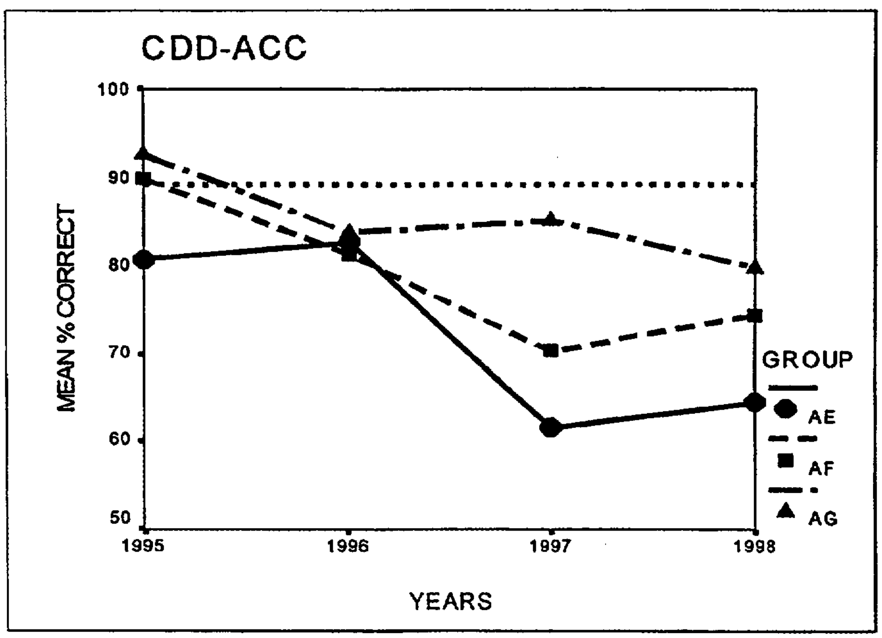

Figure 3-37. Mean performance on ANAMUKR: CDD-ACC.

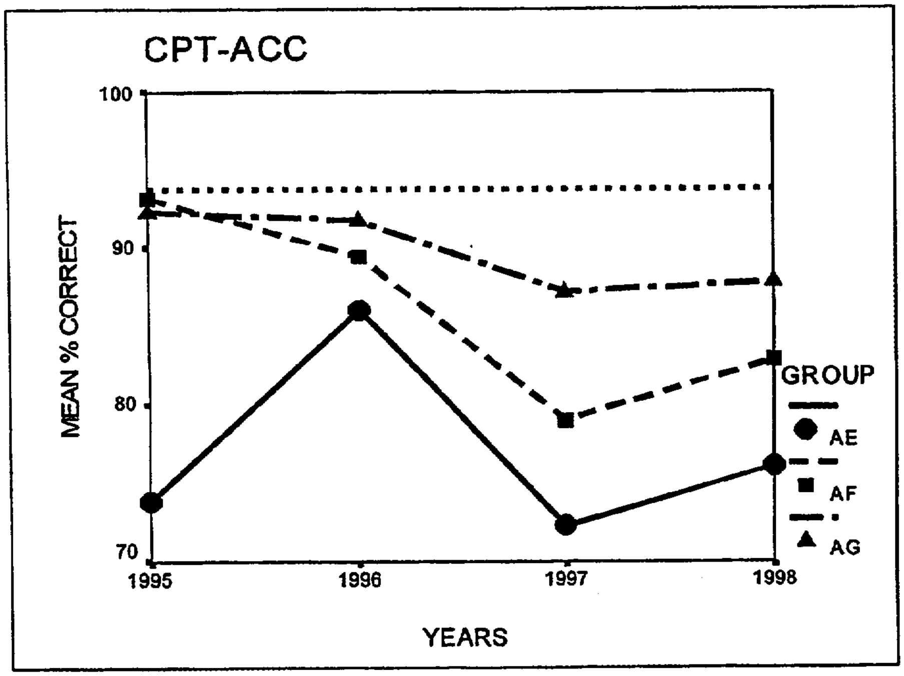

Figure 3-38. Mean performance on ANAMUKR: CPT-ACC.

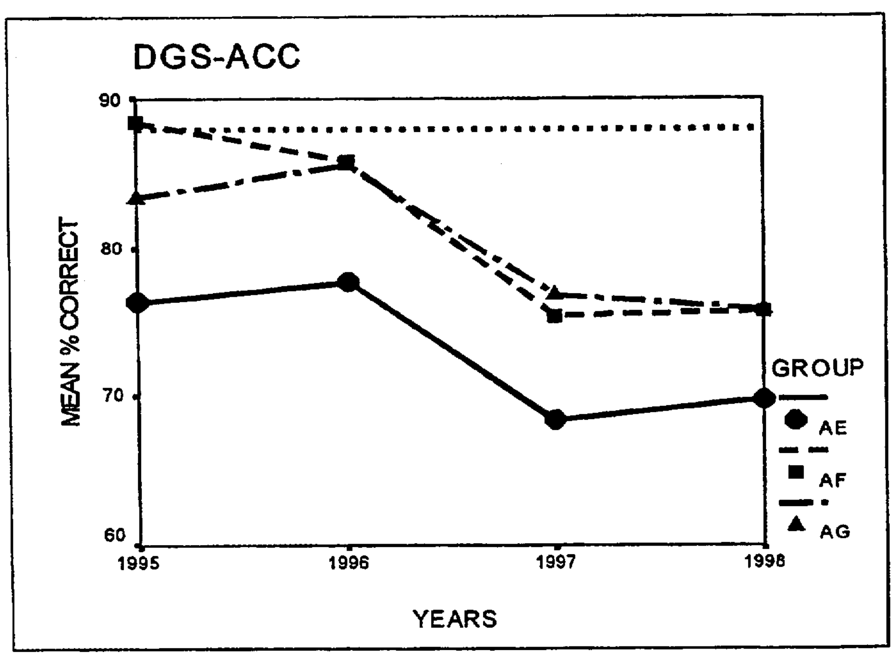

Figure 3-39. Mean performance on ANAMUKR: DGS-ACC.

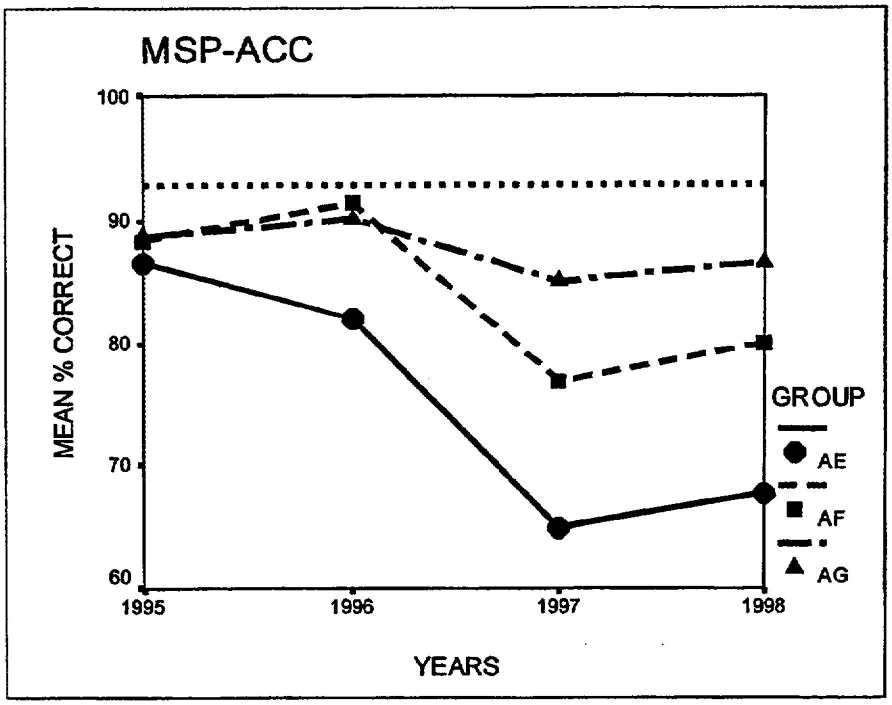

Figure 3-40. Mean performance on ANAMUKR: MSP-ACC.

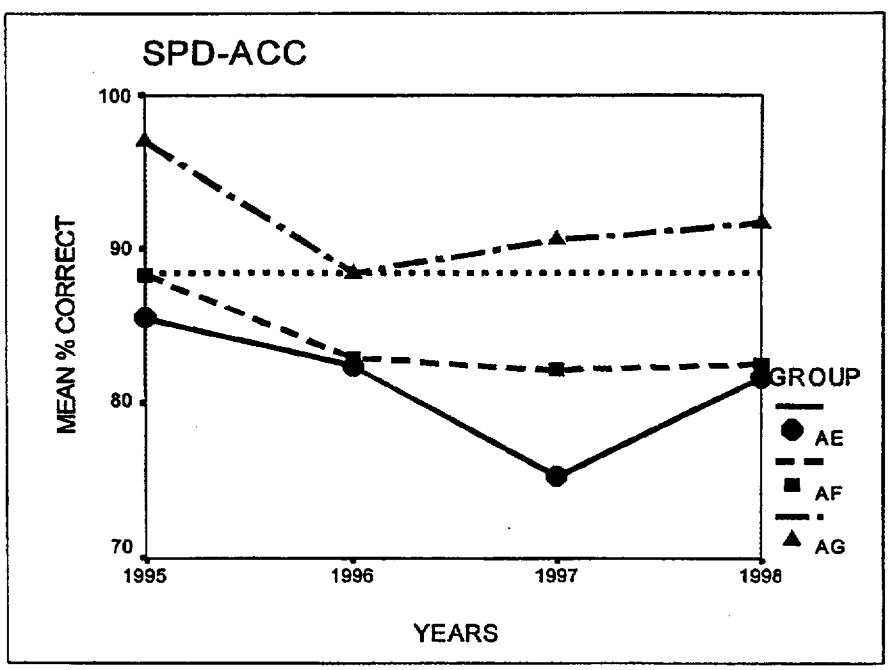

Figure 3- 41. Mean performance on ANAMUKR: SPD-ACC.

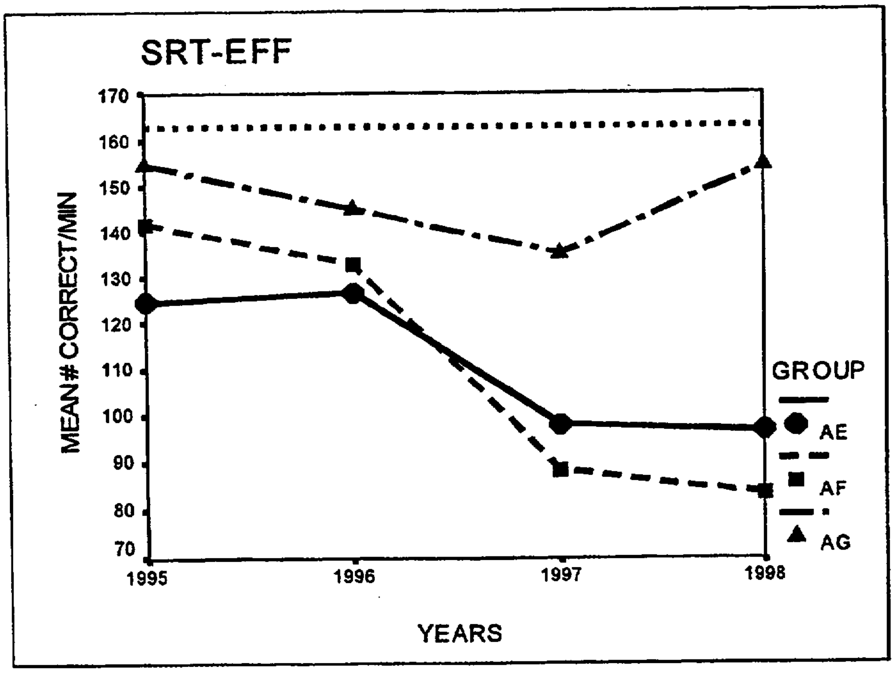

Figure 3-42. Mean performance on ANAMUKR: SRT-EFF.

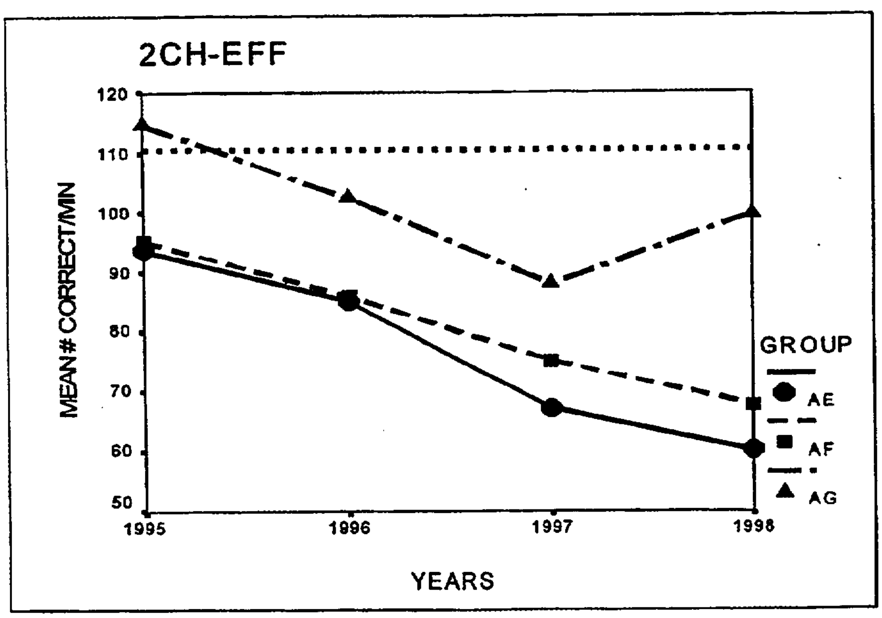

Figure 3-43. Mean performance on ANAMUKR: 2CH-EFF.

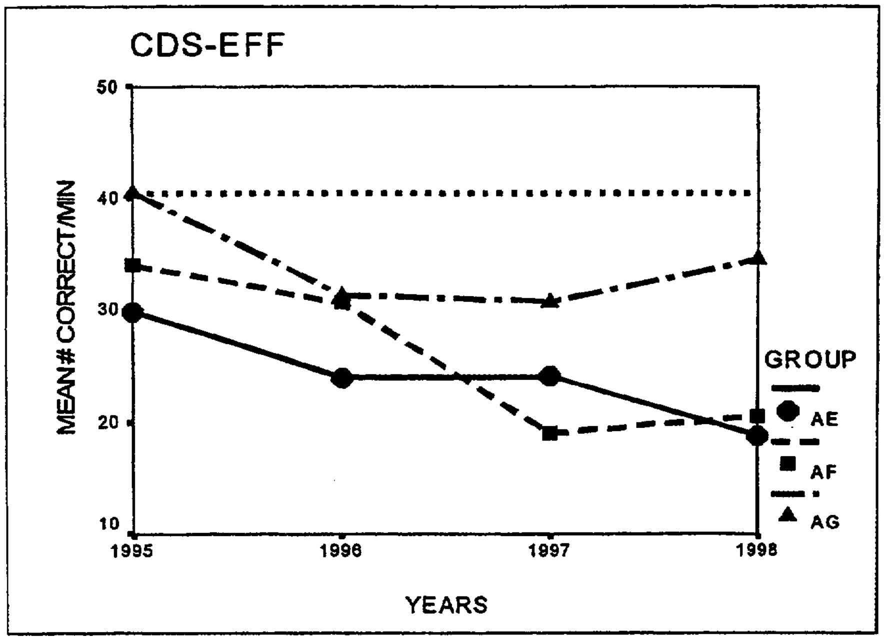

Figure 3-44. Mean performance on ANAMUKR: CDS-EFF.

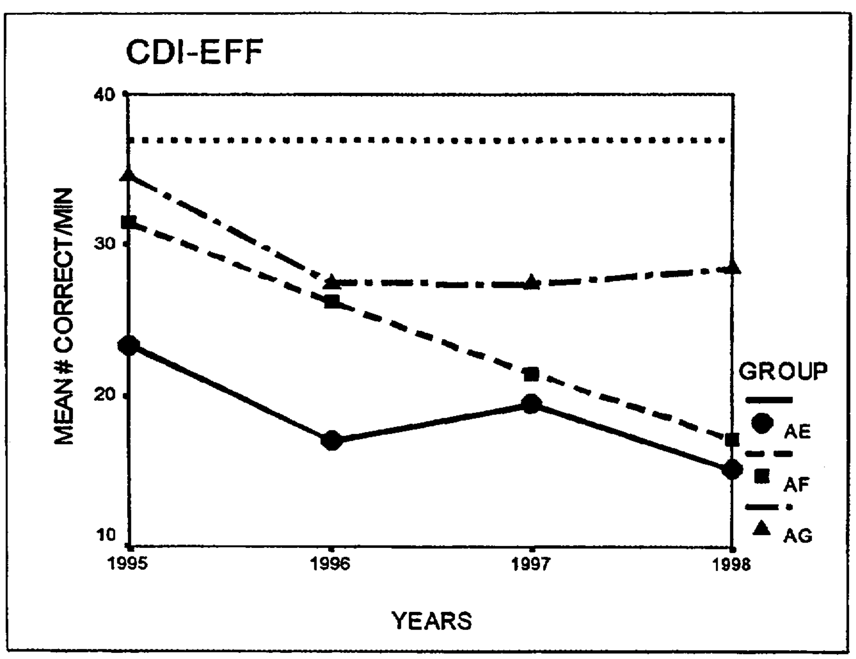

Figure 3-45. Mean performance on ANAMUKR: CDI-EFF.

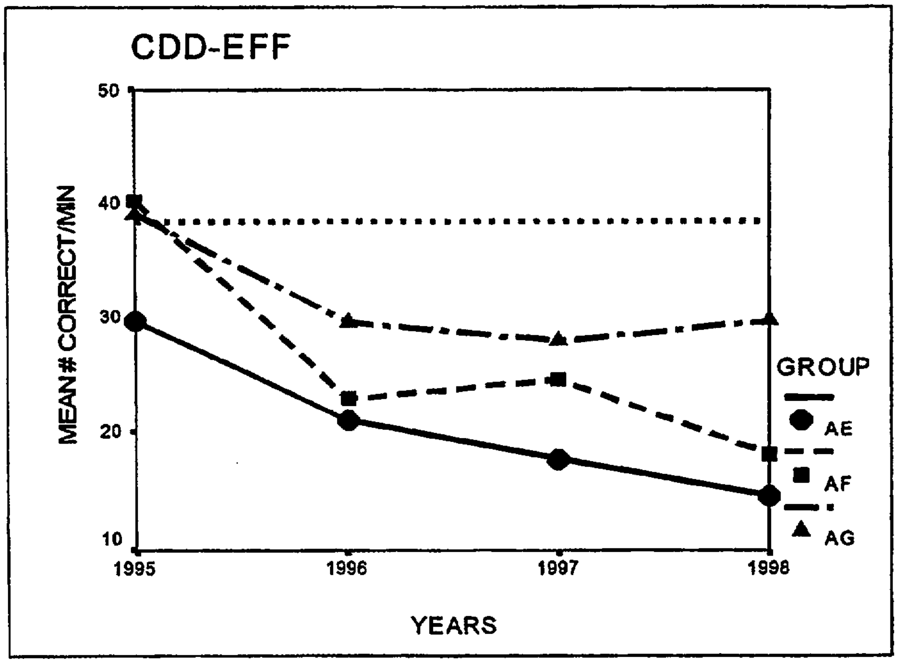

Figure 3-46. Mean performance on ANAMUKR: CDD-EFF.

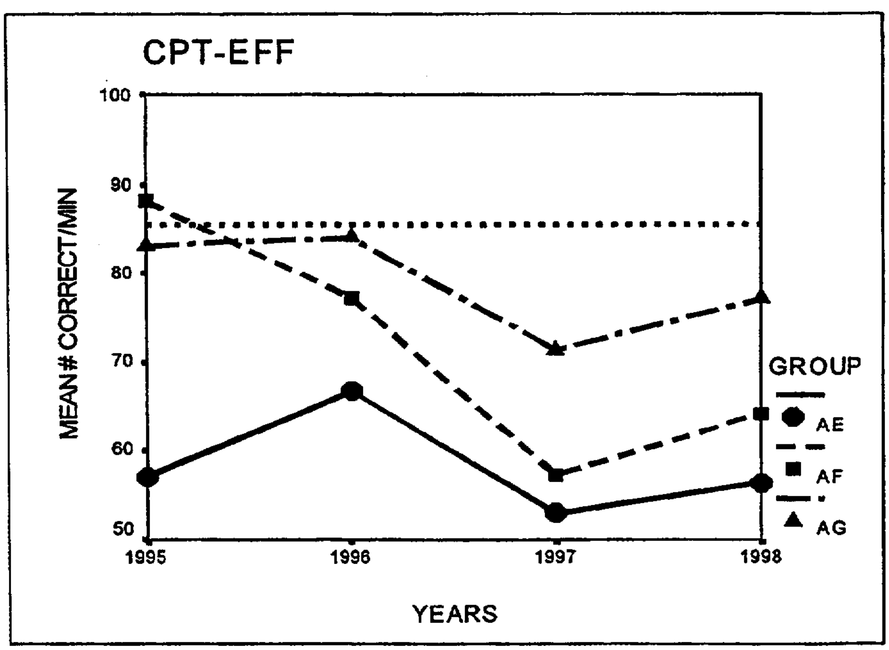

Figure 3-47. Mean performance on ANAMUKR: CPT-EFF.

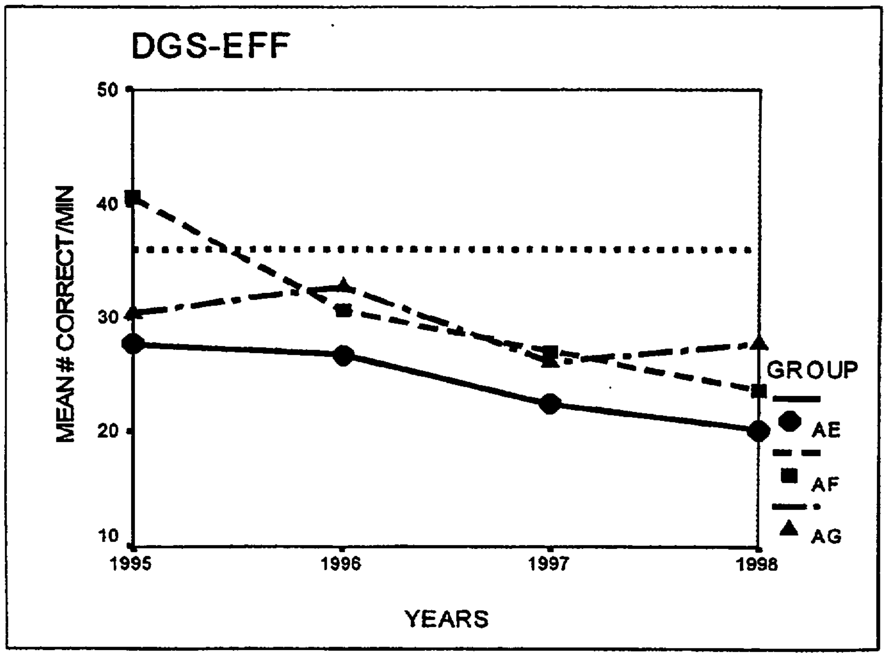

Figure 3-48. Mean performance on ANAMUKR: DGS-EFF.

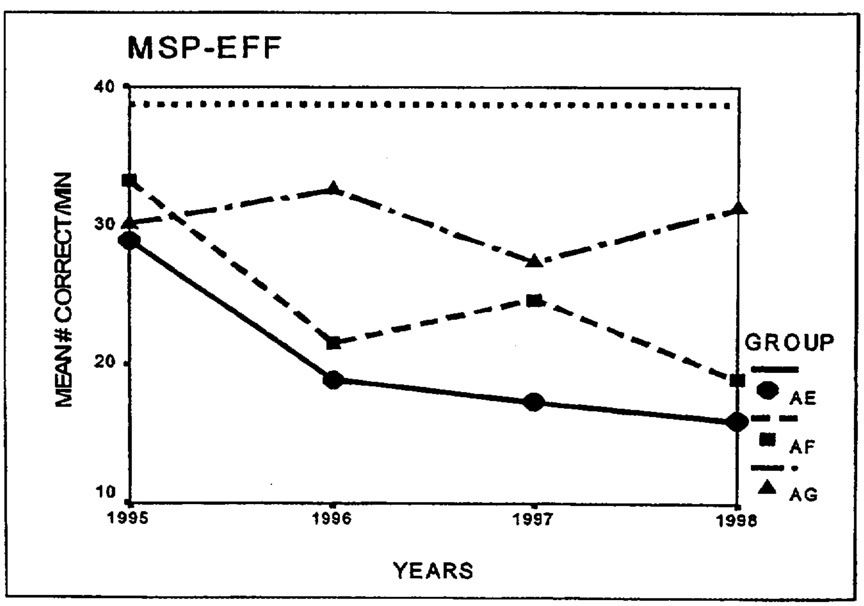

Figure 3-49. Mean performance on ANAMUKR: MSP-EFF.

Ukrainians have suffered serious medical problems as a result of the Chernobyl disaster, and their country has suffered economically since the accident. The burden of medical treatment is enormous and containment of nuclear pollution is almost impossible. Ukrainian scholars and scientists are generally in agreement that Chernobyl was one of the causes for Ukrainian independence from the former Soviet Union. For Russia the economic expenditures for environmental clean-up and treatment of the population were prohibitive.

In 1991, the Ukrainian Supreme Soviet enacted a law, which would decommission Chernobyl by the end of 1993; however, in October 1993, this law was repealed. The cost of decommissioning Chernobyl, especially in light of obtaining alternate energy sources, remains too great. The Chairman of the Ukrainian Supreme Soviet Committee on Chernobyl, Volodymyr Javorivsky said, "We will be extracting problems from the well of Chernobyl for a very long time." In light of this report, that is an understatement.

To put this report into some perspective it needs to be stated that while contamination of the eco-structure is considerable, much of the contamination affecting the Ukraine is below international standards for life-time dosages. Poor diet, the stress of living in a country where the minimum wage is $1.50 per month, and where food is a daily preoccupation, are not adequately addressed in medical reports which blame Chernobyl for all increases in disease. Yet research has shown that exposure to ionizing radiation is harmful to humans and the environment. The effects of living in contaminated areas, as well as growing and consuming contaminated food, have received little research support. The psychological concomitants of Post-Traumatic Stress Disorder are being considered in terms of recent child development studies in the Ukraine.

The Ukrainians are desirous for research support. The Ministry of Forests is particularly interested in research support to develop models for cognitive and physical decrements in performance associated with forestry workers exposed to contaminated forests. The Director of the Ukrainian Psychological Research Institute is also desirous of research support dealing with psycho-sociological problems associated with adults and children living in contaminated areas, or who have relocated from these areas. The need for assistance to help plan and guide longitudinal research has been expressed by those who have been working with the children affected by the Chernobyl disaster.

The benefits of these research proposals would be enormous for the United States. Nuclear energy is a fact worldwide. Data gathered by research efforts involving Chernobyl could impact Federal Emergency Management Administration procedures for relocating victims of similar accidents, and their medical and psychological treatment. Unfortunately, in the conduct of this research, a wealth of data was obtained that is available, however, funds were not allocated for analyses. In addition, little is known about cognitive and physical decrements in performance or stress associated with living and working in contaminated areas. Preparedness should be the bottom line in research.

Read (1993) mentions that because radiation technology was so new, there was no way to be prepared for all possible problems resulting from its use. Nonetheless, it is important that people learn from such accidents about the effects of radiation, especially considering the aftermath of nuclear war or terrorist attack. This remains one of the objectives of the present, ongoing study of the physical and neurocognitive effects of the Chernobyl accident.

SECTION 5
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