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UC 41 Health and Safety Conversion

QUARTERLY PROGRESS REPORT

ENVIRONMENTAL SAFETY ASPECTS OF NUCLEAR ROCKET FLIGHT OPERATIONS

MASTER

For

Space Nuclear Propulsion Office
Atomic Energy Commission
National Aeronautics and Space Administration

Contract SNPC-6

By

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Nuclear Utility Services, Inc.

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Vice President, Development

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I. INTRODUCTION AND SUMMARY OF PROGRESS

During the last quarter of 1964, several revisions were made in the scope and schedule of work under the present contract:

1. In view of the present status of the NERVA-RIFT Program, no great urgency attaches to prompt revision of NUS-122, the preliminary Environmental Safety Study, and the planned revision was postponed for at least one year.
2. The conduct of environmental studies bearing on NERVA-RIFT safety evaluations does not lend itself to PERT-type scheduling, which is therefore eliminated from the scope of this work.
3. The present contract period has been extended through the first quarter of 1964; thus, this report describes progress in the last quarter of 1963 rather than appearing as the annual progress report which will be issued at the end of March, 1964.

Under Task I, the major effort in the past quarter has been to further develop and refine the computer program for evaluating the environmental safety aspects of nuclear rocket operations. The computer program, named NURSE-1 for Nuclear Rocket Safety Evaluation, is operational; however, modifications are being incorporated to allow greater flexibility in the program output and to include an increased number of locations for dose calculations. Attempts have been made using data from tests with chemical explosives and scale model core mockups, to improve upon the core fragmentation model to predict size distribution.

In the last quarter of 1963, a Task III study was completed to determine the rate of vaporization of an uncooled ROVER-type core following engine operation. The study was to determine if decay heat generated after operation can be used to advantage for disposal of a rocket engine following a flight. Additional work was conducted on the environmental problems associated with premature re-entry of core fragments.

Collection of prints of existing films which will be a part of the RIFT safety film under Task IV has been started. These films will be assembled into an unedited sequence to fit the film script. Additional footage requirements will then be determined.

II. TASK I

A. Nuclear Rocket Safety Evaluation Computer Program

NURSE-1 (Nuclear Rocket Safety Evaluation) is the first in a series of computer programs designed to evaluate the hazards resulting from the accidental or intentional destruction of a nuclear rocket engine. The program can be used to evaluate the hazards which occur as a result of accidents on or near the launch site. The program is written in FORTRAN language for an IBM 7090 or 7094 computer.

The program consists of a main or calling program and six chains. In operation it is necessary to use the MAIN program, CHAIN 1, and CHAIN 6. CHAINS 2,3,4, and 5 can be used at the option of the user depending on the particular information desired. A description of the main program and the six chains is given here. Abbreviated flow charts and descriptions of the subroutines used are given in Appendix A. Complete detailed descriptions and operating instructions will be released in a subsequent report.

The NURSE program has several limitations. First, the method of calculating fission product inventories limits the use of the program to cases where there has been no previous operating history (operating histories up to 30 seconds just prior to the accident will not incur any significant errors in the doses calculated). With several minor program modifications, accidents with an engine which has had significant operating history could be evaluated. Such modifications would make the program useful for determining the hazards resulting from static tests on an engine. The second limitation is that the accident must occur at or near the ground. The calculational scheme allows initial reactor heights of less than one thousand meters. This limitation is imposed because the methods of evaluating cloud growth, rise, and diffusion are based on empirical methods not confirmed for elevated releases.

In the calculational schemes, it is assumed that the dose receptor is standing on an infinite flat plain, that is, there are no provisions in the program for incorporating changes in terrain. It is further assumed that wind direction and wind velocity at ground level remain constant for the entire period over which cloud and fallout transport are calculated; the effect of wind speed variation with altitude, however, is included.

Each of the chains performs a particular set of calculations. CHAIN 1 prepares information needed for calculation in later chains. CHAIN 1

sets up the output mesh which consists of 25 downwind positions and 5 crosswind positions at each downwind position or a total 125 mesh points. CHAIN 1 determines the cloud rise, growth, diffusion, and depletion. The fallout particle distribution is calculated as well as the ground contamination from cloud depletion. Instantaneous and integrated isotopic activities are calculated for later use in CHAIN 3 or CHAIN 5. CHAIN 1 also calculates the beta self-absorption in fallout particles as a function of beta energy and particle size.

CHAIN 2 calculates single particle beta dose to the skin resulting from particle fallout. The particle density on the ground is determined for each mesh point as a function of particle size. Dose is calculated as a function of downwind position, particle size, and total exposure time.

CHAIN 3 calculates beta and gamma doses resulting from ground contamination. Ground contamination from both cloud depletion and particle fallout are considered. Beta and gamma doses are calculated at each mesh point as a function of total exposure time.

CHAIN 4 calculates the beta and gamma whole body doses to result from the passage of a radioactive cloud. Dose rates to a receptor at each mesh point are integrated over the total cloud travel.

CHAIN 5 calculates the internal doses to the bone, thyroid, lung, and GI (gastrointestinal) tract. Inhalation doses due to cloud passage are calculated for all four organs and integrated ingestion doses to the thyroid, bone and GI tract are calculated all as a function of exposure time at each mesh point.

CHAIN 6 serves only as a termination routine being used at the completion of all desired calculations. NURSE 1 uses a library tape generated by a separate program which reads the desired information from cards, generates the library tape, and lists the information contained in the library. The write-up of this program called TAPE will be issued later.

B. Direct Gamma and Neutron Doses from Reactor Excursion

Direct prompt radiation doses from a reactor excursion have been reanalyzed, based on recently published experimental data⁽¹⁾. These data show gamma and fast neutron doses at 120 feet from the side of a Kiwi reactor equivalent to 0.15 r/MW-sec and 0.078 rad/MW-sec respectively. Conservative application of neutron spectral data from weapons tests⁽²⁾ indicate a "Quality Factor" (RBE) of ~ 7 is applicable to the neutron dose; i.e. the fast neutron dose is approximately 0.54 rem/MW-sec at the 120 foot distance.

Radiation doses at greater distances from the reactor were calculated and are summarized in Table I, based on an excursion of 10^4 MW-sec (3×10^{20} fissions), although the doses, of course, scale directly with yield.

TABLE I
DIRECT RADIATION DOSE FROM 10^4 MWsec EXCURSION

<u>Integrated Dose-10^4 MWsec</u>			
<u>Distance</u>	<u>Fast Neutrons(rem)</u>	<u>Gamma(r)</u>	<u>Total(rem)</u>
1000 ft.	26.0	10.0	36.0
3000 ft.	0.27	0.18	0.45
1 mile	5.6×10^{-3}	7.5×10^{-3}	1.3×10^{-2}

These doses are below the figures previously reported in NUS-122, which was based entirely on weapon data. Gamma and neutron leakage from the reactor, assumed to remain intact during the excursion, are factors of 6 - 10 below that from a nuclear weapon. The reduction in assumed neutron leakage is partially compensated by the application of the RBE to the measured rad dose.

The assumption of reactor integrity is, of course, open to question. During the period following the power peak, radiation leakage will increase as reactor density decreases. On the other hand, the fact that the flux may be abnormally peaked in the core center (and that increase in core density may be the initiating mechanism for the excursion) tends to reduce the leakage fraction. Further refinement of the dose calculations is possible and should be coordinated with revisions to the excursion analysis

C. Fragmentation Model

The fragmentation of a reactor core as a result of chemical explosives or nuclear transients is an important factor to be considered in the evaluation of hazards arising from accidents on the launch pad. The size distribution of radioactive particles generated in an accident has a significant effect upon calculated doses downwind of the launch site. Of special interest are particles of ingestible and inhalable size.

The results of a series of tests using chemical explosives placed in various configurations both internally and externally to scale model cores were reported by the Aerojet-General, Corp.⁽³⁾ Two different core models were

used in the tests and varying weights of charges were used to fragment the model cores. Following the test, the core fragments were recovered and a size distribution of the particles was obtained from a sieve analysis.

To obtain a fragmentation model various exponential fits have been tried and compared to the data, the two best fits to the data being:

$$V_c = \left(\frac{X_o}{X} \right)^c \quad (I-1)$$

$$V_c = \int_{-\infty}^X \frac{1}{\sigma \sqrt{2\pi}} \exp \frac{-(\ln X/m)^2}{2\sigma^2} dx \quad (I-2)$$

where: V_c is the fraction of core mass which has a size of "X" or smaller

X_o is the largest size produced

X is the particle size

c is a constant for any given explosive size

The latter fit is a logarithmic normal distribution where "m" is the mean size and σ the logarithmic standard deviation.

However well equation I-1 may fit the size distribution data, the parameters X_o and c cannot be related to explosive size and consequently equation I-1 is of no value.

The second form is slightly more useful although neither m nor σ can be related to the explosive weight within any reasonable degree of accuracy. Figure 1 shows $(-\log_e m)$ as a function of explosive weight and Figure 2 shows the value of σ as a function of explosive weight. As can be seen, the scatter in the data is so great that any relationship that is derived for values of these parameters is quite tenuous.

However, fitting the values of "m" and " σ " into the form: $m = aW^C$ and $\sigma = \text{Log}_e(bW)^S$ where W is the explosive weight yields the results shown in Figures 3 through 11. The solid lines are plots of the analytical expression and the circles represent the data obtained from the explosive tests.

FIG. 9. PARTICLE SIZE DISTRIBUTION
TEST PO-76

FIG. 10. PARTICLE SIZE DISTRIBUTION
TEST PO-78

FIG. 11. PARTICLE SIZE DISTRIBUTION
TEST PO-86

III. TASK II

During the last quarter of 1963 no time was spent on scheduling RIFT related studies.

IV. TASK III

A. Re-entry of Radioactive Particles

Further study has been devoted to the problems associated with the premature re-entry of radioactive fragments of a NERVA core following destruct sequence. The review of particle-people interaction probabilities and effects has been continued, using data available from LMSC and the Aberdeen Proving Ground. Effects evaluations are being re-examined in the light of medical application of small sources for internal irradiation of tissues, and of therapeutic and diagnostic usage of X-Radiation.

Visits were made to Columbia University (Drs. E. Quimby and G. Merriam), Sloan Kettering, Institute of Cancer Research (Dr. D. Karnovsky), Dr. A Cippallano (Dermatologist associated with NYU) and Dr. I. Ariel (Radio-therapist associated with BNL).

In general, discussion of the problem with the medical group has not been fruitful. Beta radiations as used by the radiotherapist are not determined by either a surface (or contact) dose or dose over a larger volume of tissue. Sources are ordinarily arranged to maintain a certain minimum dose to a specific tissue volume without regard to the dose uniformity in specific cellular components. Most of those visited did not anticipate problems with a single particle interaction, although the dosimetry concepts used were questioned.

B. Graphite Sublimation in RIFT

A brief study was made of graphite sublimation as a mechanism for reactor self-destruction.⁽⁴⁾ The study indicated that loss of graphite after reactor shutdown from full power operation under hard vacuum condition will result in partial destruction of the reactor. This destruction can be enhanced by adding reactivity to compensate for loss of coolant flow. The vaporization is probably limited to about 20% of the core graphite. The remainder of the core may be expelled from the reactor vessel.

Post-Operational heating rates resulting from fission product decay heat and subcritical delayed neutron fission were calculated for three cases:

- A. A hard shutdown to approximately $-0.034 \delta k/k$
- B. Shutdown to $-0.01 \delta k/k$
- C. 0.25 shutdown to $-0.0025 \delta k/k$

The effect of negative reactivity and subcritical fission on the temperature of the reactor core after shutdown is shown in Figure 12.

Cumulative graphite losses from the core for various shutdown margins are shown in Table II. The effect of shutdown margin is very pronounced but it must be recognized that both loss of carbon and temperature rise will result in a decrease in reactivity. Based on current design⁽⁵⁾, only a fraction of the reactivity loss could be compensated by motion of the control reflectors and the reactor could be maintained close to critical for no more than a few seconds.

TABLE II
CUMULATIVE LOSS OF GRAPHITE
(Per cent) After Shutdown

TIME (Sec)	SHUTDOWN REACTIVITY ($\delta k/k$)		
	-0.034	-0.010	-0.0025
3	-	-	0.01
10	-	1.1	9.5
20	0.1	10.0	28.4
30	0.5	16.6	42.6
60	5.2	27.9	72.5
120	11.8	43.1	100.0
10 ³	43.1	75.6	

An example of the probable sequence which could be expected if the reactor were programed for deliberate destruction after shutdown would be:

1. 0-1 sec.-coolant flow stops, poison sections rotated out to hold reactor .0025 subcritical, temperature of core increases to 5200°F.
2. 1-3 sec.-control drums continue to ramp in reactivity to compensate for temperature rise to 6400°R, graphite sublimation negligible.
3. 3-10 sec.-temperature reaches maximum of 8200°R at about 7 seconds; internal peak pressure is 8.3 atm. and carbon loss rate is 2.3%/sec. At 10 seconds the reactor is subcritical by at least \$5 and further fission power is negligible, temperature is 8130°R all internal structural components and 9.5 % of the graphite would be vaporized and the reactor would be largely destroyed.

4. 10-120 sec-decay heat available during this period is sufficient to vaporize an additional 10 % of the graphite.

Although complete vaporization of the core is improbable, the high temperatures achieved during the post-operational period enhance the rate of diffusion of fission products from the fuel and should result in a much lower residual inventory.

Carbon loss during normal operation was calculated to be negligible at the nominal operating temperature, although it may be rapid in hot spots. Based on a 6000°F maximum hot channel temperature, a carbon loss of 2×10^{-3} pounds per pound of hydrogen flow was calculated. Carbon loss in hot spots will tend to be self-correcting as the decreased concentration of moderator should result in a reduction in temperature.

Restart of the reactor after shutdown from a full duration power run will require continued coolant flow in the intervening period. The minimum flow necessary to prevent core damage as a result of graphite loss and, more critically, melting of important structural members, is a function of shutdown margin, but it is estimated to be not less than 10% of nominal full flow. Cooling may be required to maintain core integrity until activation of the post-operational destruct system, if restart is not planned.

Thermodynamic properties of graphite used in this study were based on a report by Rand Corporation⁽⁶⁾ covering the full range of temperatures and pressures of interest to this study.

Heat loss from the core by conduction or radiation was assumed negligible during the initial 120 seconds of shutdown. The only effective mechanism for heat loss is the sublimation of graphite and discharge of the carbon vapor.

C. Counter Measure Criteria

Comments were provided to SNPO-Washington on the "Counter Measure Criteria" presented at the December Rover Flight Safety Panel Meeting.

V. TASK IV

A revised outline of the script was completed; a new, unclassified narrative of the entire script was then written and keyed to a description of each scene. Running time for each scene and each section of the narrative was estimated. The entire script was then edited to bring its estimated total running time from over an hour down to forty-two minutes. The draft was submitted to the Rover Project Safety Office and a detailed discussion was held with them. Revisions to incorporate their comments are in process.

Visits were made to Aerojet, Lockheed, NRDL and LASL to review films made at those locations and also at Argonne and Sandia. A number of useful scenes were identified and copies of the footage were ordered.

VI. TRIPS MADE AND MEETINGS ATTENDED

The following trips were made and meetings attended during the last quarter of 1963.

TRIPS MADE

<u>Date</u>	<u>Location - Purpose</u>	<u>Visitors*</u>
9/29 to 10/4	Albuquerque, N.M., Aerospace Nuclear Safety Meeting	CRMc, MIG, WFB, ADA
10/2 to 10/3	Oak Ridge, Tenn., ORNL Health Physics Information Meeting	LFG
10/10	Germantown, to discuss the script of RIFT safety film	WFB
10/11	Germantown, to review methods of working more closely; stretchout of contract period. Task III discussion to set up procedures for brief studies	MIG, MLC
10/21 to 10/28	Los Alamos, Azusa, NRDL and Sunnyvale to view and discuss existing film footage for RIFT safety film	WFB
11/6	NRDL, to discuss Phase I studies and review the hazards analysis program	MIG, MLC
11/7	Davis Campus, Univ. of Calif., review work directed at long-term effects of chronic ingestion by dogs of varying Sr-90 levels	MIG
11/12	Azusa, Calif. to discuss computer program for RIFT hazards evaluation with Lockheed	MLC
11/18 to 11/20	New York, American Nuclear Society Meeting	ADA
11/29	Germantown, to present results of investigation of NERVA core evaporation	MIG, RD
12/2 to 12/4	Pittsburgh, to attend Rover Flight Safety Panel, technical session on SWET program	MIG, CRMc

<u>Date</u>	<u>Location-Purpose</u>	<u>Visitors*</u>
12/10 to 12/11	Germantown, information meeting on aerospace safety	CRMc, MIG, ADA, RD
12/17	Pittsburgh, to review WANL program for shutdown heat distribution, discuss possible experimental program to determine behavior of vaporized material	CRMc
12/26 to 12/28	New York Memorial Cancer Hospital, Columbia Presbyterian Hospital, to review practice of using radiating microspheres in radiotherapy.	LAB

* Initials used refer to the following:

CRMc	Dr. C. Rogers McCullough
MIG	Dr. Morton I. Goldman
WFB	Mr. William F. Banks
LFG	Mr. Luis F. Garcia
LAB	Mr. Lester A. Barrer
ADA	Mr. Albert W. DeAgazio
RD	Mr. Roy Denham
MLC	Mr. Melvin L. Couchman

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- (5) "Aerojet General RIFT Safety Review Program-Nerva Systems Description" AEC-7690.005 Revised (Confidential-RD), August 1963.
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APPENDIX A

This appendix contains brief descriptions of the various chains of the computer program and the functions of each subroutine. Flow sheets of the entire program follow the descriptions.

1. MAIN Program

The MAIN Program reads the control and title cards and prints the operating instructions on line. It also allows for restarting at the beginning of Chains 2, 3, 4, or 5. This function is included to allow for program recovery with the minimum possible loss of computer time in the event of an accidental or intentional program termination. MAIN uses no subroutines; however, in the normal starting case, it calls CHAIN 1.

2. CHAIN 1

The use of CHAIN 1 is necessary for running any of the subsequent chains. CHAIN 1 uses the following subroutines:

FACTOR	CALC 1
READ 1	CONC 1
XANDY	CONC 2
DIFF	SLFAB
INTZ	OUT 1
FLOUT	PAGE
XQW	OTND
TAPE	GSFR

A description of the above subroutines follows. Once the above subroutines are executed, CHAIN 1 calls the next chain requested.

a. Subroutine READ 1

The READ 1 subroutine reads and checks the input. If an input error is found, a description of this error is printed off-line and CHAIN-6 is called.

READ 1 first reads the deposition velocities for each of six deposition groups and twenty-five downwind positions from the library tape. The following input quantities are then read; the stability class, the mean ground level wind speed, the release height, the chemical energy released, the total nuclear energy released, the maximum and "typical" fallout particle sizes, the core volume and density, and the fraction of total gaseous and the fraction of the total solid fission products released. At the user's option, the deposition velocity for any deposition group and any downwind position may be read, overlaying those values contained in the library. A check of the above input is

then made for consistency and range.

b. Subroutine XANDY

Subroutine XANDY calculates the downwind and crosswind position at which doses will be calculated. There are 25 downwind positions ranging from 10 meters to 10^7 meters from the origin. Each of these positions is a factor of $10^{0.25}$ further from the origin than the preceding position. There are 5 crosswind positions for each downwind position. The first of these is on the centerline. The other four are at 1.5, 3.0, 4.5 and 6.0 times the value of $\sigma_y(x)$, respectively. This subroutine also determines the area and the boundary positions for the region associated with each of the 125 mesh points.

XANDY also calculates the 8 exposure times used in integrated dose calculation. These exposures times are 1 hour, 2 hours, 8 hours, 1 day, 1 week, 1 month, 1 year, and infinity (100 years). Additionally, XANDY calls subroutine DIFF.

c. Subroutine DIFF

Subroutine DIFF determines cloud growth and diffusion with time resulting both from chemical and nuclear energy and from meteorological diffusion. Meteorological diffusion parameters are read from the library tape. The total energy release is determined and with this data, cloud rise, growth and diffusion is calculated. DIFF calculates $\sigma_y(x)$ and $\sigma_z(x)$, the diffusion parameters. Here "x" is the downwind distance from the origin. DIFF also calls subroutine INTZ.

d. Subroutine INTZ

The INTZ subroutine calculates

$$\int_0^x \frac{dt}{\sigma_y(t)}$$

for the 25 downwind (x) positions. This quantity is needed to determine cloud depletion.

e. Subroutine FLOUT

The FLOUT subroutine determines fallout density on the ground as a function of fallout particle size for 9 particle size groups.

A minimum and maximum distance from the origin is determined for each particle size. A log-normal distribution of particles between minimum and maximum points on the ground in each particle size group is determined at every mesh point.

f. Subroutine XQW

Subroutine XQW calculates the ground level cloud concentration at all mesh point. It also calculates the downwind cloud depletion and ground contamination due to cloud depletion at each mesh point.

g. Subroutine CALC 1 (CALC 2 and CALC 3)

The CALC 1 subroutine determines the parameters of any particular isotope using indexing information contained on the library tape. CALC 1 calls CONC 1 and CONC 2.

CALC 2 differs only in that it calls CONC 3 and CALC 3 calls CONC 4.

h. Subroutine CONC 1 (CONC 4)

Subroutine CONC 1 (and CONC 4) calculates the instantaneous concentrations of each isotope at any time. The generalized Bateman equation is used.

i. Subroutine CONC 2 (CONC 3)

Subroutine CONC 2 (and CONC 3) calculates the integrated concentration of each isotope between any two given times. The integrated Bateman equation is used.

j. Subroutine GSFR

The GSFR subroutine calculates the gaseous and particulate release

fractions of each isotope. GSFR uses indexing information contained on the library tape and input information to calculate these functions.

k. Subroutine TAPE 1

The TAPE 1 subroutine reads the isotopic decay and internal dose parameters from the library tape. A determination is made of the chain requested. If CHAIN 3 or CHAIN 5 have been requested, GSFR and CALC 1 are called, yielding instantaneous and integrated isotopic concentrations. These values are stored on tape for use later in either or both of these chains.

l. Subroutine SLFAB

Subroutine SLFAB calculates the beta energy self-absorption factors for fallout particles. These factors are calculated as a function of particle size and beta energy.

m. Subroutine OUT 1

The OUT 1 subroutine prepares and writes all the output for CHAIN 1. OUT 1 makes use of subroutine PAGE.

n. Subroutine FACTOR

Subroutine FACTOR calculates factorials from 1! through 20!

o. Subroutine PAGE

Subroutine PAGE is called by the various output routines whenever a page change is desired. PAGE increases the page number by one, changes the page, writes the heading and the page number and writes the title.

p. Subroutine OTND

In order that NURSE-1 might be terminated by the operator with minimal loss of time in restarting, a check of Sense Switch 6 is made in many places through out the entire program. If the operator has depressed Sense Switch 6, OTND is called. OTND then terminates the program in such a fashion as to facilitate simple restarting.

3. CHAIN 2

CHAIN 2 calculates the single particle beta dose. The subroutines used by CHAIN 2 are:

FACTOR	CONC 3
SBETA	PAGE
CALC 2	OTND

A description of SBETA follows. FACTOR, PAGE, OTND, CALC 2 and described previously.

Subroutine SBETA

Subroutine SBETA, uses information generated in CHIAN 1. Single particle beta doses at each downwind position are calculated as a function of particle size and exposure time. The density of fallout particles on the ground at each mesh point is calculated. SBETA calls CALC 2.

4. CHAIN 3

CHAIN 3 is used when the dose from ground contamination is desired. The following subroutines are used in CHAIN 3:

FACTOR	PAGE
DOSIN	OTND
GRDOS	

A discussion of DOSIN and GRDOS follows. FACTOR, PAGE AND OTND were described previously.

a. Subroutine DOSIN

The DOSIN subroutine integrates the ground dose to a receptor in the region where the receptor is located.

b. Subroutine GRDOS

Subroutine GRDOS, using information generated in CHAIN 1 calculates the beta and gamma ground dose. This dose is a result of ground contamination from both particle fallout and cloud depletion. The dose is

output for each mesh point as a function of exposure time. GRDOS integrates the dose contribution from surrounding regions. DOSIN is called to integrate the region in which the receptor is located.

5. CHAIN 4

The routines in CHAIN 4 calculate the direct whole body dose due to cloud passage. CHAIN 4 includes the following subroutines:

FACTOR	GSFR
CLOUD	CLSDS 3
TRANS	CALC 3
ENERGY	CONC 4
TIMEO	PAGE
CLINT	OTND

FACTOR, GSFR, CALC 3, CONC 4, PAGE, and OTND have been described previously. Additionally, CHAIN 4 calls the next chain requested.

a. Subroutine CLOUD

Subroutine CLOUD calculates the beta and gamma doses resulting from the passage of a contaminated cloud. The doses are calculated for each mesh point. CLOUD calls GSFR, CALC 3, TRANS, ENERGY, TIMEO and CLINT.

b. Subroutine TRANS

Subroutine TRANS calculates cloud transport, growth, diffusion and depletion.

c. Subroutine ENERGY

The ENERGY subroutine integrates beta and gamma activities over all energies.

d. Subroutine TIMEO

Subroutine TIMEO calculates the dose resulting from direct radiation from the reactor to the receptors.

e. Subroutine CLINT

The CLINT subroutine integrates the dose to a receptor over the entire cloud with the exception of a sphere, one meter in radius, surrounding the receptor. If the receptor is immersed in the cloud, CLINT calls subrouting CLSDS 3.

f. Subroutine CLSDS 3

Subroutine CLSDS 3 integrates the dose to a receptor immersed in the passing cloud. It integrates over a sphere, one meter in radius, surrounding the receptor.

6. CHAIN 5

CHAIN 5 is used for calculating internal doses. It requires information generated in CHAIN 1. CHIAN 5 includes the following subroutines:

INDOS	PAGE
INGEST	OTND
IDOUT	

PAGE and OTND were described previously. CHAIN 5 calls CHAIN 6.

a. Subroutine INDOS

The INDOS subroutine using information generated in CHAIN 1, calculates the internal doses. The organs considered are the lung, the thyroid, the bone and the GI tract. INDOS calls INGEST.

b. Subroutine INGEST

Subroutine INGEST calculates the fraction of the cloud and ground contamination that reaches the organ through a particular ingestion route.

c. Subroutine IDOUT

The IDOUT subroutine prepares and writes the internal dose output.

MAIN

CHAIN 1

SUBROUTINE

READ 1

SUBROUTINE
XANDY

SUBROUTINE DIFF

FLOUT

SUBROUTINE

XQW

SUBROUTINE
INTZ

SUBROUTINE
GSFR

SUBROUTINE
CALC 1

SUBROUTINE
CALC 2

SUBROUTINE
CALC 3

SUBROUTINE
CONC 1,4

SUBROUTINE
CONC 2,3

SUBROUTINE
SLFAB

SUBROUTINE
OUTI

SUBROUTINE TAPE 1

CHAIN 2

SUBROUTINE

SBETA

CHAIN 3

SUBROUTINE

DOSIN

SUBROUTINE GRDOS

CHAIN 4

SUBROUTINE CLOUD

SUBROUTINE
TRANS

SUBROUTINE
ENERGY

SUBROUTINE
CLSD3

SUBROUTINE
TIMEO

SUBROUTINE
CLINT

CHAIN 5

SUBROUTINE

INDOS

SUBROUTINE
INGEST

SUBROUTINE IDOUT

CHAIN 6

SUBROUTINE
FACTOR

SUBROUTINE
PAGE

SUBROUTINE
ONTD