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RSAC-6 Radiological Safety Analysis Computer Program

B. J. Schrader
D. R. Wenzel

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RSAC-6
Radiological Safety Analysis Computer Program
B.J. Schrader D.R. Wenzel
Calculates the radiological consequences of a release of radioactive material to the atmosphere

RSAC-6 is the latest version of the RSAC program. It calculates the consequences of a release of radionuclides to the atmosphere. Using a personal computer, a user can generate a fission product inventory; decay and in-grow the inventory during transport through processes, facilities, and the environment; model the downwind dispersion of the activity; and calculate doses to downwind individuals. Internal dose from the inhalation and ingestion pathways is calculated. External dose from ground surface and plume gamma pathways is calculated. New and exciting updates to the program include the ability to evaluate a release to an enclosed room, resuspension of deposited activity and evaluation of a release up to 1 meter from the release point. Enhanced tools are included for dry deposition, building wake, occupancy factors, respirable fraction, AMAD adjustment, updated and enhanced radionuclide inventory and inclusion of the dose-conversion factors from FGR 11 and 12.

RSAC6 is written in Fortran 77 and runs on a MS-DOS compatible computer. RSAC6 can be used to model complex accidents ad radiological consequences to individuals from the release of radionuclides to the atmosphere. RSAC6 is issued with a companion program, RSAC+, a user friendly interface written to assist users in preparing input to RSAC6.

RSAC6 calculates complete progeny in-growth and decay during all accident phases. The calculation of fission product inventories in particularly useful in the analysis of accidents where the short-lived radionuclides change rapidly as a function of decay time or accidents with criticality excursions. RSAC6 also has provisions for calculating release from an operating reactor. RSAC6 fission product calculations are valid primarily for high enriched fuels. Provision is also made of users to import fission product, actinide and activation product inventories calculated using other codes such as ORIGEN2 when desired.

Radionuclide inventories can be fractionated and decayed to simulate transport through a process or clean-up system such as HEPA filters. Inventory fractionations may be done by chemical group, by element or by fraction of the entire radionuclide inventory. Complex release scenarios to the atmosphere can be modeled with RSAC6. Releases to the atmosphere can be simulated using either linear or exponential release models.

RSAC6 calculates meteorological dispersion in the atmosphere using Gaussian plume diffusion for Pasquill-Gifford, Hilmeier-Gifford and Markee models. A unique capability is the ability to model Class F fumigation conditions, the meteorological condition that causes the highest ground level concentrations from an elevated release.
Doses may be calculated for various pathways including inhalation, ingestion, ground surface, air immersion, water immersion pathways. Dose calculations may be made for either acute or chronic releases. Internal doses (inhalation and ingestion) are calculated using the ICRP-30 model with dose conversion factors from FGR 11. External factors are calculated using FGR 12. This is a significant move from the previous DOE factors that were used in RSAC5.

This code is completely validated and verified in accordance with applicable standards.

Radioactive releases from various nuclear facilities may contribute to radiation exposure through a number of pathways. External exposures by direct radiation from plumes or deposited radionuclides, internal exposures due to inhalation and ingestion of radioactive material. The Radiological Safety Analysis Computer Program (RSAC-6) calculates the consequences of the release of radionuclides to the atmosphere. Using a personal computer, a user can generate a fission product inventory; decay and ingrow the inventory during transport through processes, facilities, and the environment; model the downwind dispersion of the activity; and calculate doses to downwind individuals.

A fission product inventory can be calculated from a reactor operating history or can be used to simulate a nuclear criticality accident. Radionuclide inventories can also be directly input into RSAC-6 if desired. Source term modeling allows for complete progeny ingrowth and decay during all accident phases. RSAC-6 release scenario modeling allows fractionation of the inventory by chemical group or element. RSAC-6 also models the effects of high-efficiency particulate air (HEPA) filters or other cleanup systems. RSAC-6's meteorological capabilities include Gaussian plume diffusion for Pasquill-Gifford, Hilsmeier-Gifford, and Markee models. RSAC-6 possesses the unique ability to model Class F fumigation conditions. Optionally, users can supply plume standard deviations (σs) or atmospheric diffusion (χ/Qs) to the code as input data. RSAC-6 also includes corrections for deposition (wet and dry) plume rise (jet and buoyant), resuspension, release in a room and building wake. Doses are calculated through inhalation, immersion, ground surface, and ingestion pathways, and cloud gamma dose from semi-infinite plume model and finite plume model. A fifty-mile population dose, using Regulatory Guide 1.109 modeling, is also available.

RSAC+, a menu-driven companion program to RSAC-6, assists users in creating and running RSAC-6 input files. RSAC+ is written in a fourth generation database language and runs on any personal computer that supports the RSAC-6 code. With RSAC+, a user can modify input files easily. It also allows the user to insert, edit, add, copy, move, or delete sets of instructions in RSAC-6. RSAC+ stores each problem set in a separate file, distinguished by a unique file extension. RSAC+ checks all fields to ensure that data are in an appropriate range for the variable and that there is consistency in an input series.

RSAC is an excellent tool to evaluate both accident conditions in emergency response scenarios and evaluation of safety basis accident conditions.

RSAC History

RSAC was originally developed and written in assembly language (MAP) for the IBM 7044/44 in 1966 by R. L. Coates and N. R. Horton (Coates and Horton 1966). In 1968, a FORTRAN version of the program was prepared by L. C. Richardson (Richardson 1968). Since 1968, RSAC has undergone substantial revision.

In 1973, RSAC-2 was issued by D. R. Wenzel (Wenzel 1973) to

- Add input and output options

- Change the inhalation dose calculations (lung and gastro-intestinal tract)
- Change the numerical integration methods for cloud gamma dose calculations
- Change the gamma-ray buildup factor model
- Revise radionuclide yields and half-lives in the standard library
- Refine output format for ease of reading
- Reduce computer memory requirements.

In 1982, RSAC-3 was issued (Wenzel 1982) to

- Add a fifty-mile population dose calculations
- Use the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (NRC 1977a) for ingestion dose calculations
- Use the International Commission for Radiological Protection (ICRP) Lung Dynamics Model for inhalation dose calculations
- Use the Dolphin and Eve Gastro-intestinal Tract Model
- Improve error detection.

After undergoing an extensive verification and validation, RSAC-4 (Wenzel 1990) was enhanced and issued in 1990 to

- Convert the program FORTRAN 77
- Execute RSAC-4 on a personal computer
- Use internal dose conversion factors from DOE/EH-0071 (DOE 1988a) and external dose-rate conversion factors from DOE/EH-0070 (DOE 1988b)
- Add dose summary tables
- Add an ingestion dose model for an acute release
- Increase the number of organs in the dose calculations
- Include water immersion dose calculations

- Program calculated plume rise for either jet or buoyant plume
- Revise fission yields and half-lives
- Add radionuclides to the standard library
- Update the photon data library
- Enhance error diagnostics
- Include validation and verification necessary to meet the additional requirements for software imposed by ASME-NQA-1, “Quality Assurance Program Requirements for Nuclear Facilities” (ASME 1989).

In 1994, RSAC-5 was issued (Wenzel 1994) to

- Add an option to calculate cloud-gamma doses expressed in external dose equivalent
- Add a variable particle size option for inhalation dose calculations
- Resolve the over depletion for ground level releases during stable meteorology that was observed in earlier versions of RSAC
- Add a reflective meteorological model to better model diffusion below the mixing depth
- Include additional radionuclides to more accurately model the U-235 fission chain
- Add a dose summing option
- Incorporate a simplified notation for radionuclide identification
- Include a capability to read radionuclide inventories from external files
- Correct errors observed in earlier versions of RSAC for the finite-plume model integration for cloud-gamma dose calculations and large plumes
- Add meteorological diffusion using Pasquill-Gifford parameters
- Include an option to simulate the release of fission products from an operating reactor
- Update forage and vegetation yields

- Include an option to read ingestion transfer parameters from an external file
- Refine the model for ingestion dose calculations from an acute release
- Add a companion program, RSAC+, that assists the user in preparing an input file for RSAC-6.

The sixth and current version, RSAC-6, is a major revision to the program. Numerous areas were

- Add additional radionuclides to the program library
- Use internal dose conversion factors from Federal Guidance Report No. 11 (EPA 1988) and external dose-rate conversion factors from Federal Guidance Report No. 12 (EPA 1993)
- Provision to calculate doses at distances of less than 100 m
- Correction of minor errors identified in the program
- Printout of radionuclides in a logical order
- Add of default lung clearance classes to provide the maximum dose based on each element
- Entry of radionuclide input in either upper or lower case characters
- Elimination of a discontinuity in the leakage function
- Addition of an option to allow the user to enter a respirable fraction for inhalation dose calculations
- Addition of an option to allow the user to enter an occupancy factor for ground surface dose calculations
- Incorporation of editorial changes in program output.

- Enhanced method for estimation of the building wake effect
- Evaluate the instantaneous release to a room
- Evaluate the resuspension of particulate activity
- Enhanced method for evaluation of dry deposition
- Perform calculation of an effective σ_y and σ_z when X/Q is directly input

RSAC-6 consists of nine program series. Each program series performs a type of calculation and operates together or independently of the others, depending on the analysis being performed. These series are identified by input series lines of multiples of 1000. A summary of each of the program series follows.

1000 Series—Fission Product Inventory Calculation

RSAC-6 allows the user to establish an inventory of fission products (and subsequent decay products) by simulating the operation of a thermal reactor. The user can simulate steady-state, transient, or cyclic reactor operation. A refueling option is also available. After establishing the reactor operating history, the user can then specify the fractional release of the radionuclide inventory by individual element; by groups of elements (solids, halogens, noble gases, cesium, or ruthenium); or by a single release fraction for the entire inventory.

RSAC-6 calculates inventories for fission products only. The RSAC-6 nuclear data library (see Appendix B) contains selected activation products, actinides, and the daughters of actinides in addition to the fission products. Inventories for activation products and actinides are not calculated by RSAC-6; however, they can be added to the inventory by using the radionuclide direct input section of the program. Subsequent sections of the program calculate the radioactive decay and doses from these additional radionuclides.

The model used by RSAC-6 to calculate fission product inventories is simple compared to the model used in the ORIGEN2 program (Croff 1980, RSIC 1991). RSAC-6 is simple to run and requires less computer time than ORIGEN2. In general, the RSAC-6 model calculates fission product inventories well. However, it does not calculate inventories for activation products or actinides. While the RSAC-6 model corrects for depletions of fission products by neutron activation, it does not calculate all of the subsequent radionuclides that are produced by the neutron activation of fission products. When irradiation times are long, the burnup is relatively high, or the enrichment of the fuel is low, inventories of radionuclides produced primarily by the activation of fission products (Cs-134, Pm-147, Sm-151, Eu-154 and Eu-155) can differ from ORIGEN2-calculated inventories by more than 20%. When doses from these radionuclides are significant compared to the other fission products, users should use a more sophisticated computer program such as ORIGEN2 and import the final inventory using the 2000 Series input to RSAC-6. RSAC-6 can then be used to decay the inventories and simulate additional reactor operation or fuel handling accidents such as a criticality.

The 1000 Series of RSAC-6 can be reentered as many times as desired to modify the radionuclide inventory. One of the options in this series is to fractionate the radionuclide inventory and to simulate removal of activity by cleanup systems such as HEPA filters. The inventory can be fractionated by chemical group, element, or entire inventory.

The capability of RSAC-6 to model the fission product inventory as a function of time during a hypothetical criticality accident is shown in Figure 1-1. The fission product inventories for solids, halogens, and noble gases are shown individually as a function of time. The RSAC-6 input for analyzing this accident is presented in Example 8 in Section 5. The assumptions used in the example are from demonstration purposes only and should not be applied directly to other criticality accidents calculations unless determined to be applicable. Initially, the radionuclide inventory in the aged reactor fuel involved in the criticality accident is constant. The criticality occurs during a short duration, during which large quantities of short-lived fission products are produced. The solid fission products are fractionated by a factor of 0.001 and the halogens are fractionated by a factor of 0.25 to give the activity released to a process off-gas system. All of the noble gases are assumed to be released. While the solids initially begin to decay, the ingrowth from the short-lived noble gases increases the activity of the solids by approximately a decade. The solids then decrease by three decades when passing through the first HEPA filter. The solids activity then increases by approximately two decades during the transport time to the final two HEPAs. The final two HEPAs decrease the activity of the solids by approximately five decades, after which decay of the short-lived noble gases again builds up the activity of the solids. After about 20 minutes during downwind transport, the solids activity reaches a maximum and slowly begins to decrease. RSAC-6 is the only program that models all aspects of a release to the atmosphere from source term generation to downwind dose.

2000 Series—Direct Radionuclide Input

This series allows users to input a radionuclide inventory from an external file or to directly input the amounts of radionuclides to be used in subsequent calculations.

3000 Series—Dose Summary Option

This series allows doses from different exposure pathways and multiple RSAC-6 calculations within the same input run to be summarized, added, and reported in summary tables. This option has strict operating guidelines [see Section 4.1, *Dose Summary Option Control Line (3000)*].

4000 Series—Radionuclide Data Constants Change

This series allows users to change standard data constants for radionuclides such as half-life, branching ratio, and fission yield. Changes are temporary for the current RSAC-6 run and do not make permanent changes to the RSAC-6 libraries. However, users cannot change photon energies for radionuclides or dose conversion factors.

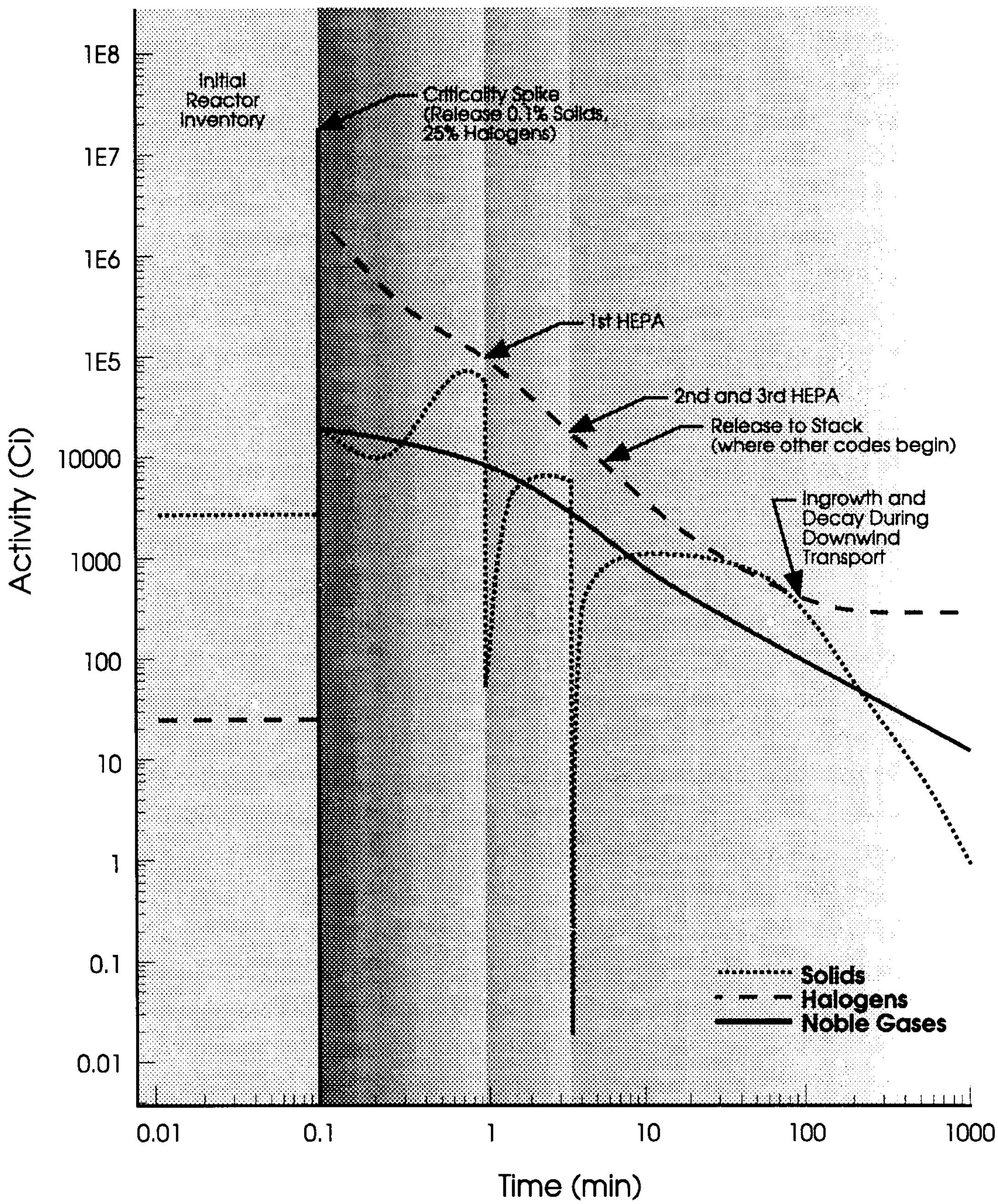

Figure 1-1. Changing inventory during criticality accident.

5000 Series—Meteorological Data Input

This series allows the user to specify meteorological conditions at the time of release and to calculate diffusion, dispersion, and depletion factors.

This input series of RSAC-6 must normally be entered before any dose calculations are requested. (The 8000 Series, Fifty-Mile Radius Dose, is an exception to this rule.) After establishing basic meteorological parameters (such as stack height, wind velocity, and mixing layer depth), the user specifies points of interest for dose calculations at downwind and/or crosswind positions.

RSAC-6 models the release of radioactivity from containment structures using exponential functions. Instantaneous and continuous releases are modeled using a single exponential function. Complex release scenarios can be modeled using a series of up to 10 exponential functions. These functions decay the radionuclide inventory while it is held up by the containment structure before it is released.

Atmospheric diffusion parameters can be input directly by the user or calculated by RSAC-6. RSAC-6 calculates plume standard deviations (σs) developed for three different conditions (see Appendix C). Hilsmeier-Gifford σs (Clawson et al. 1989) were developed for desert terrains and releases from a few to 15 minutes. Markee σs (Clawson et al. 1989) were also been developed for a desert terrain; however, they were developed for releases from 15 to 60 minutes in duration. Pasquill-Gifford σs are presented in the NRC Regulatory Guide 1.145 (NRC 1982) and by Slade (1968) from the Prairie Grass experiments for effluent releases with durations of 10 to 60 minutes.

Other meteorological options available in RSAC-6 are corrections for plume rise using models by Briggs (1969), building wake corrections (Yanskey et al. 1966), and plume depletion using modeling of Markee (1967) and Chamberlain (1953).

6000 Series—Decay of Radionuclide Inventory for Printout

This series allows the user to calculate the radioactive decay of the entire radionuclide inventory or selected radionuclides for printout. Decay of the radionuclide inventory for subsequent dose calculations is not done in this series, but in the 1000 Series. If downwind distances have been previously specified in the meteorological section of the program (5000 Series), decay times are calculated for each downwind position. Alternately, the user can directly specify decay times in this series. Radionuclide inventory printout options are then available. Inventories for activation products and actinides are printed only when 2000 Series input has been used to enter these radionuclides.

7000 Series—Internal/External Dose Calculation

This series allows the user to perform a variety of dose calculations. The radionuclide source term for these calculations is the radionuclide inventory created and operated on in the 1000 and 2000 Series. An internal dose can be calculated for up to 23 organs in addition to the committed effective dose equivalent (CEDE) for the inhalation or ingestion pathways. Internal doses are calculated using dose conversion factors from Federal Guidance Report No. 11(FRG 1988). Ingestion doses from a chronic release are calculated using models described in Regulatory Guide 1.109 (NRC 1977a). Because of the lack of a consensus model, equations for calculating ingestion doses from an acute release have been developed specifically for RSAC-6. Standard ingestion constants are provided in the program; however, the user can alter any of the constants. External dose can also be calculated for up to 23 organs in addition to the external effective dose equivalent (EDE) for the ground surface, and air immersion pathways. The air immersion model should be used with caution to ensure that the plume has diffused to the ground level and that the plume size is large compared to the mean free path of the gamma rays. Otherwise, using the air immersion model can result in significant error in the dose calculation. External doses are calculated using dose-rate conversion factors from Federal Guidance Report No. 12 (FRG 1993). External exposure from a release to a room and internal exposure from resuspension are also available.

8000 Series—Fifty-Mile Radius Dose Calculation

This series permits the user to calculate committed population doses within a fifty-mile radius of a nuclear facility. The same internal and external dose models available in the 7000 Series are available in the 8000 Series. The user must supply population and diffusion/dispersion coefficients for five, 10-mile radii in each of the 16 compass sectors as input.

9000 Series—Cloud Gamma Dose Calculation

RSAC-6 calculates cloud gamma doses (in addition to the air immersion model provided in the 7000 Series input) using either a finite plume model or a semi-infinite cloud gamma model. The finite plume model is accurate for any plume size, location, or release point. However, compared to the air immersion or semi-infinite models, it requires longer computer time to perform calculations. When the plume has diffused to ground level and is large compared to the mean free path of the gamma rays, both the semi-infinite and the air immersion models give accurate results. However, as noted in the 7000 Series discussion in this section, significant errors can result when the proper conditions for these simplified models do not exist. Whenever in doubt, the user should use the finite plume cloud gamma model. By comparing the results of the finite plume model with the semi-infinite plume model, users can establish when the simplified models can be used.

Conclusion

RSAC-6 is a computer code that can be confidently used to evaluate radiological releases to the environment. The fact that the code has been verified and validated to existing standards provides confidence that the results are consistent and confident.