DOCUMENTATION FOR THE FRAMES-HWIR TECHNOLOGY SOFTWARE SYSTEM, VOLUME 1: SYSTEM OVERVIEW

Project Officer
and Technical Direction:

Mr. Gerard F. Laniak
U.S. Environmental Protection Agency
Office of Research and Development
National Environmental Research Laboratory
Athens, Georgia 30605

Prepared by:

Pacific Northwest National Laboratory
P.O. Box 999
Richland, Washington 99352
Under EPA Reference Number DW89937333-01-0

U.S. Environmental Protection Agency
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Frames-HWIR Technology Software System

System Overview

Summary

By October 1999, the U.S. Environmental Protection Agency (EPA) must issue a proposal for a revised rule for managing, storing, and disposing of hazardous wastes under the Resource Conservation and Recovery Act. This revised rule is known as the Hazardous Waste Identification Rule (HWIR). To develop the proposal for this revised rule, EPA must identify criteria based on protection of humans and other living organisms by which treated or mixed hazardous waste would no longer be considered hazardous.

To develop criteria based on protecting the health of humans and other living organisms, the EPA supported the development of a comprehensive environmental exposure and risk analysis software system. The Pacific Northwest National Laboratory modified its Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES), under the direction of EPA, to produce the FRAMES-HWIR Technology Software System. This report provides a broad overview of the system.

The EPA chose the FRAMES software concept because it would allow 1) the incorporation and linkage of existing and future models within its framework and 2) access to different databases. Based on requirements provided by the EPA, the FRAMES-HWIR Technology Software System will estimate risk across multiple pathways of exposure to both humans and other living organisms and produce scientifically acceptable risk information. The system answers the question: "at what concentration level would a chemical be nonhazardous to humans and other living organisms?"

The system was developed under a quality assurance program that met the requirements of several federal agencies. Additional information is available in referenced documents.

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What is the FRAMES-HWIR Technology Software System?

By October 1999, the U.S. Environmental Protection Agency (EPA) must issue a proposal for a revised rule for managing, storing, and disposing of hazardous wastes under the Resource Conservation and Recovery Act. This revised rule is known as the Hazardous Waste Identification Rule (HWIR). To develop the proposal for this revised rule, EPA must identify criteria by which treated or mixed hazardous waste would no longer be considered hazardous.

To develop criteria based on protecting the health of humans and other living organisms, the EPA supported the development of a comprehensive environmental exposure and risk analysis software system. The Pacific Northwest National Laboratory (PNNL) modified its Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES), under the direction of EPA, to produce the FRAMES-HWIR Technology Software System (Whelan et al. 1997).

This report provides a broad overview of the system, answering such questions as why the assessment is being conducted, why EPA selected the FRAMES system, what EPA needed the system to do, and how the system was designed to meet those needs. This report also addresses the processes that were followed to ensure that the system was developed, based on sound scientific principles and engineering practices. Companion documents, as listed in the references at the end of the report, describe specific system components.

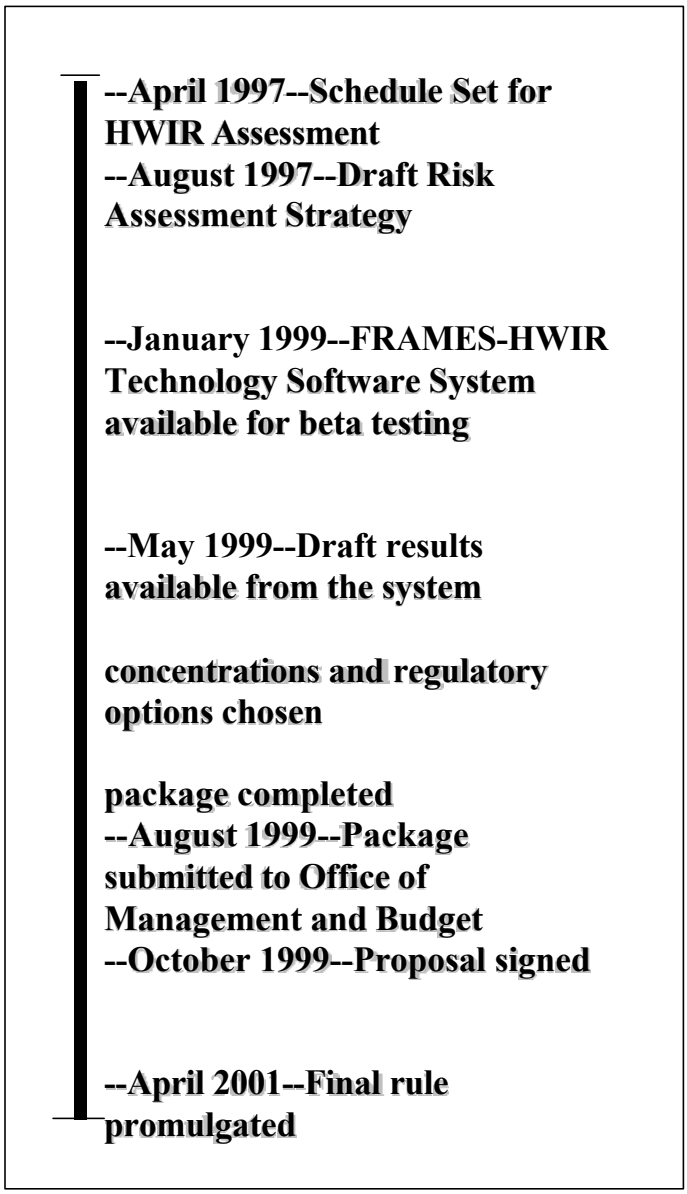
Why is the HWIR Assessment Being Conducted?

The purpose of the HWIR assessment is to develop standards for chemical concentrations in hazardous waste before it is disposed of. These standards would protect the health of humans and other living organisms, yet allow the waste to exit the hazardous waste category under the Resource Conservation and Recovery Act, Subtitle C. These standards would cover both mixed waste and treated waste. This waste would then be relisted as industrial waste under the Act, Subtitle D. Under current regulations, listed hazardous waste is always regulated as hazardous, even after it has been treated, regardless of the concentration of the chemicals. Furthermore, waste that is mixed or derived from a hazardous waste is still considered hazardous. These regulations were developed to protect the public from unacceptable risks resulting from mismanaging treated, mixed, or diluted hazardous wastes.

As a result of several court-ordered and Congressional actions between 1991 and 1996, EPA must initiate replacement regulations for hazardous wastes. The new proposed rule will be published by October 31, 1999, and the final rule will be published by April 30, 2001.

The regulatory changes under consideration are for managing, storing, and disposing of hazardous waste. These changes address actual and/or potential risks to the health of humans and other living organisms from exposures across all environmental media, including air, soil, surface water, and groundwater. EPA is conducting a risk assessment that will

- integrate the calculations of release of a chemical from the waste management facility, the transportation and fate of the chemical through the environment, and exposure and risk to humans and other living organisms across potential methods of being exposed (for example, for humans, drinking contaminated well water, showering in contaminated water, and breathing contaminated air)
- evaluate uncertainty and variability inherent in all risk assessments
- evaluate the transformation of certain chemicals (for example, mercury) in groundwater into byproducts and their associated toxicity
- evaluate the use of toxicity data 1) that other federal agencies have used in establishing regulatory levels or toxicity benchmarks or 2) that have been peer-reviewed, published, and submitted to EPA in comments on earlier HWIR documentation
- evaluate the degree of risk posed at water supply wells near waste



Timeline for HWIR Implementation

management, treatment, or storage facilities.

The HWIR assessment will identify wastes currently listed as hazardous that can exit the category of hazardous waste. The FRAMES-HWIR Technology Software System, therefore, must estimate these risks in a manner that integrates results from many environmental sources, pathways of exposure, and types of receptors (humans, plants, and animals).

The assessment will calculate risk to humans by considering lifestyle factors that might affect risk (for example, farmers and their children could experience a different level of risk from community residents and their children because a farm family has access to additional crops and livestock and often gets water from a well system instead of treated city water). The assessment will calculate risk to living organisms by considering a variety of plants and animals commonly found near actual hazardous waste facilities and the food they eat or provide to other animals and humans. For both humans and other living organisms, the assessment will consider risks from simultaneous exposures to a single chemical by adding exposures from potentially contaminated air, groundwater, surface water, soil, and biological media.

This characterization will be conducted for a select number of representative sites across the United States. The results will then yield a national distribution of individual risks from individual constituents released from hazardous waste facilities. The characterization will rely on actual site data, when available, rather than hypothetical site and receptor descriptions. The approach also considers that many data depend on each other (for example, climate, hydrology, and plant and animal life) and maintains correlations as a function of site location.

Why Did EPA Select the FRAMES Software Concept?

Both the U.S. Department of Energy (DOE) and EPA have used comprehensive risk modeling software for a number of years to estimate risks from various activities and sites. In 1994, both agencies recognized that they had similar needs for a system that integrated across all environmental media (air, groundwater, surface water, overland, etc.) to calculate risks to both humans and other living organisms. In response to this need, PNNL developed the concept for FRAMES. DOE and EPA co-funded the development of this software over several years. The first version of the software was released in October 1998.

One of the reasons that the FRAMES concept was chosen for the HWIR assessment is its ability to allow any number of models to be placed within it with relatively minimal modification to those models. This "plug and play" ability is possible because FRAMES views all models as common objects and provides common-data specifications. This approach was used for the FRAMES-HWIR Technology Software System to allow existing EPA models such as ISC-short term, which evaluates contaminant concentrations in air, and EXAMS, which evaluates contaminant concentrations in water, to connect with newly developed models so that all environmental media were considered.

What Kind of System Was Necessary?

To provide the type of multimedia assessment EPA needs to assess the risks to humans and other living organisms, the FRAMES-HWIR Technology Software System must have certain characteristics and behaviors. These requirements include the following:

1. The system must be implemented on one or more stand-alone IBM-compatible personal computers. EPA chose not to use more advanced computational capabilities so that no additional computers had to be purchased and stakeholders could run the software if so desired. Therefore, the system was designed to run on a Pentium (586)-compatible computer with a 200-MHz processing speed, 64 megabytes of RAM, and a 6-gigabyte hard drive or greater.

2. The system must be developed to operate in and have applications compiled for a Microsoft® Windows® 95 environment because that is the current and expected environment within which EPA computers are working.

3. The system must perform as time-effectively as possible given the speed with which results will be needed to assess risks as part of the rulemaking activities.

4. The system must use "object-oriented" programming. This type of programming treats modules and processors as real-world objects and allows for easy linking of modules through data specifications. Without such programming, scientifically sound models developed elsewhere could not be used for the HWIR assessment. Such programming also allows for the system to be used for other purposes in the future.

5. The system must accommodate existing environmental models in a variety of older and current programming languages. The system framework will be programmed in a more recent language, specifically Digital Visual Basic.

6. The system must be able to access databases containing statistical information, environmental-parameter information, site-survey data, meteorological data, and chemical-properties data that will be needed to assess the risks.

7. The system must be able to produce a variety of output files, from one part of the system to another, resulting in information that will allow EPA to visualize risk levels to humans and other living organisms from chemical-specific concentration levels.

8. The system must have a user interface, although limited information is expected from the user. All data needed to assess risks should already be loaded into the system, and the user need only pick the chemical of interest, concentration level, site, and location for input and output files. The user will have some control in accessing results and exporting them to other applications for additional data analyses.

9. The system must allow assessment of risks across multiple environmental media and multiple pathways of exposure to humans and other living organisms, and produce scientifically acceptable risk information.

How Does the System Work?

The FRAMES-HWIR Technology Software System consists of a user interface and a series of processors within a system framework. The interface and processors work together to answer the question, "At what concentration level before disposal would a particular chemical be nonhazardous to humans and other living organisms near a particular facility?" A variety of factors affect how this question is answered, for example,

< the number of concentration levels for a particular chemical. The HWIR Assessment considers a range of concentration levels for each chemical based on a number of factors, including the process that generated that chemical, the chemical properties, and the level of known toxicity.

< the number of chemicals to be evaluated. The assessment will evaluate chemicals currently listed as hazardous, including organic chemicals and metals that have adequate toxicity, chemical, and physical property information for conducting an assessment.

- < the definition of nonhazardous. The EPA will define “nonhazardous” once risks have been assessed to humans and other living organisms.

- < the varying environmental conditions among sites. The assessment will evaluate typical environmental conditions found across the nation near industrial waste facilities.

- < the different types of waste management systems. The assessment will evaluate contamination that could emanate from aerated tanks, land application units, landfills, surface impoundments, and waste piles.

- < the types of receptors living nearby. The assessment will consider exposures and risks to community residents and their children, home gardeners and their children, farmers and their children, and recreational fishers and their children within a 2-kilometer radius of the facility as well as plants and animals typically found within that same radius of a particular facility.

The user provides input through the system user interface to select the facility to be evaluated, which types of waste management units to use, which chemicals to consider, and the location of files containing key information. The information simulated is shown in the box on the opposite page. Statistical information is used as input to the definition of a particular site. In this context, site refers to a waste management facility, which might contain one or more waste management units, such as aerated tanks, landfills, land application units, surface impoundments, or waste piles. Whenever possible, data collected at actual waste management facilities are used to fill the databases from which site information is defined. However, when such data are not available, the system selects appropriate information from either regional or national data of the same type, using in part the statistical information. For example, if a site in Georgia were missing data related to rainfall, the system would select a distribution of regional rainfall data. If regional data were not available, the system would select a distribution of national rainfall data to provide the necessary information.

CONTAMINANTS
- Organics (29)
- Metals (13)

SOURCE TYPES
- Landfill
- Land Application Unit
- Surface Impoundment
- Aerated Tank
- Waste Pile

SOURCE TERM CHARACTERISTICS
- Mass Balance
- Multimedia/Multiphase Partitioning
- Source Degradation (anaerobic and aerobic)

SOURCE RELEASE MECHANISMS
- Erosion
- Volatilization
- Runoff
- Leaching
- Particle Suspension

TRANSPORT MEDIA
- Air
- Soil
- Vadose Zone
- Groundwater
- Surface Water

FATE PROCESSES
- Chemical/Biological Transformation
- Linear Partitioning (water/air, water/soil, air/plant, water/biota)
- Nonlinear Partitioning (metals in vadose zone)
- Chemical Reaction/Speciation

AGE GROUPS FOR HUMAN RECEPTORS

Calculated	Reported
Infant < 1 year	Infant < 1 year
Child-a 1-5 years	Child 1-12 years
Child-b 6-11 years	Young adults and
Child-c 12 -19 years	adults 13+ years
Adult 20+ years	Summation of Groups

INTERMEDIA CONTAMINANT FLUXES

Source	!	Air (volatilization, resuspension)
Source	!	Vadose Zone (leaching)
Source Surface Soil	!	Local Watershed Soil (erosion, runoff)
Air	!	Watershed/Farm /Habitat Soil (wet/dry deposition)
Air	!	Surface Water (wet/dry deposition)
Air	!	Vegetation (deposition/uptake)
Farm/Habitat Soil	!	Vegetation (root uptake)
Watershed Soil	!	Surface Water (erosion, runoff)
Surface Water	!	Aquatic Organisms (uptake)
Surface Water	!	Sediment (sedimentation)
Vadose Zone	!	Groundwater (percolation)
Vadose Zone	!	Air (volatilization)
Groundwater	!	Surface Water
Soil	!	Vegetation (uptake, deposition)
Vegetation, Soil, Water	!	Beef and Dairy (uptake)

FOOD CHAIN
- Human (Farm)
- Human (Aquatic)
- Ecological (Aquatic Habitat)
- Ecological (Terrestrial Habitat)

RECEPTORS

Human
- Resident (adult and child)
- Farmer (adult and child)
- Home Gardener (adult and child)
- Recreational Fisher (adult and child)
- Summation of Receptors

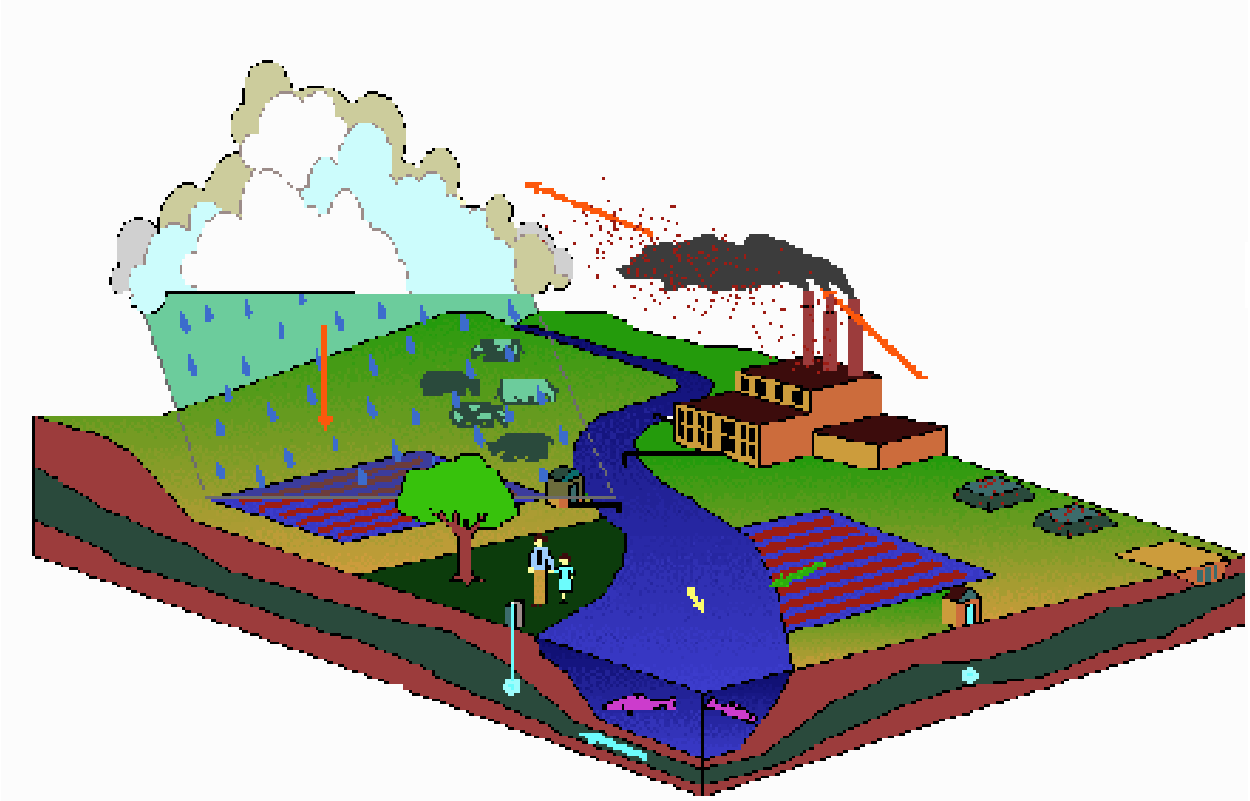
Ecological

Mammals, Birds, Soil Biota, Terrestrial Plants, Aquatic Biota, Sediment Biota, Aquatic Plants, Amphibians, Herpes, and Reptiles.

EXPOSURE ROUTES
- Ingestion (plant, meat, milk, aquatic food, water, soil, breast milk)
- Inhalation (particulates and gases, including showering)
- Direct Contact (soil, water)
- Summation of Inhalation
- Summation of Ingestion
- Summation of Inhalation and Ingestion

HUMAN AND ECOLOGICAL RISK ENDPOINTS
- Human Cancer Risk
- Human Noncancer Hazard Quotient
- Ecological Population and Community Hazard Quotients

Parameters Considered in the HWIR Assessment



Exposure Pathways to Humans and the Environment

The system collects the types of data identified in the box from databases specified by the user to create a full definition of a particular site. This information is used by a group of models to simulate the transport of contamination through the environment. Each model in the system requires specific parameters, which are provided through a series of site definition files. In trying to provide all the data that models need, these files may contain duplicate information. The data may also indicate that a particular site is not appropriate to run (for example, when data conflicts or when a similar site has recently been assessed). Such conditions could result in a large amount of unnecessary data traveling through the system, slowing performance. Therefore, before risks are assessed, the risk assessors review the data to optimize the data set and ensure smooth performance.

The system then assesses risks through a complex modeling protocol that looks at the release of contaminants in a variety of ways; transport of those contaminants through the environment; exposure of humans, animals, and plants; and the resulting risks or hazards posed by such exposures. For each particular site, the appropriate models are chosen for implementation. Models available include those to simulate the following:

- < contaminant release from aerated tanks, landfills, land application units, surface impoundments, or waste piles
- < contaminant movement through the air, groundwater, soil, watersheds, rivers, and lakes, ponds, or wetlands
- < direct contact of humans, plants, and animals with the waste contaminants
- < contamination of drinking water wells, farms (through irrigation water or direct atmospheric deposition), plants, and animals (both on land and in water bodies)
- < ingestion by humans and animals of contaminated materials such as food and soil
- < risks to humans, plants, and animals from all potential methods of exposure being modeled.

The system then tabulates the calculated risks to allow EPA to determine what chemical levels will protect human and ecological health.

What Results Does the System Produce?

The FRAMES-HWIR Technology Software System produces a series of data curves for different time periods that show the range at which a chemical would be considered nonhazardous to humans and other living organisms before it was placed into a disposal system. These curves will vary not only by the amount of time in which the chemical has been in the environment, but also by the type of facility, the type of environmental conditions, and the types of humans or animals that were exposed. For example, a landfill facility in a region with a large amount of rainfall and very permeable soil might release a chemical more quickly into the environment than a similar facility in an arid environment with a more dense soil. EPA staff will evaluate the curves produced from the system, as well as regulatory, cultural, and other factors, to determine what pre-disposal concentrations protect humans and other living organisms.

How Good Are the Results from the System?

Knowing that the results from the system would be used to help determine appropriate concentration levels for chemicals to safeguard the health of humans and other living organisms, the EPA took a number of precautions to ensure that the system would produce scientifically accurate, useful information.

First, the overall system was developed under a documented quality assurance process (Gelston et al. 1998). This process defines quality as the ability of the software to meet user needs. Meeting these needs starts with a shared understanding of how the software must perform and continues throughout the software life cycle of design, development, testing, and implementation through attention to details. The process was designed for compatibility with similar processes used by other government agencies. For example, the quality process

compares favorably with that in the U.S. Environmental Protection Agency Directive 2182*, System Design and Development Guidance* (EPA 1997). It also compares favorably with the Office of Civilian Radioactive Waste Management's *Quality Assurance Requirements and Description, Supplement I, Software* (OCRWM 1995).

Second, the system was designed based on comments received from the EPA Science Advisory Board, environmental organizations, and other reputable scientists. These comments directed EPA to ensure that the risk assessment

< evaluated risks from all contaminant pathways concurrently
< considered parameter sensitivity to statistical variations
< used additional toxicity data for ecological impacts
< ensured that real, verifiable data were used as input
< enlisted the review of scientists both within the Agency and outside it.

Third, to ensure that all components of the FRAMES-HWIR Technology Software System interact appropriately when placed into the software system, EPA requested that module and processor developers meet a set of expectations in the areas of quality assurance and testing. In the area of quality assurance, module and processor developers were expected to

< use an appropriate approach to quality assurance and documentation

< work with related-media modelers to ensure consistency of assumptions/data transfer between media (for example, a modeler creating a vadose zone module might need to ensure consistency with a modeler creating an aquifer module that would use vadose zone module results as input)

< provide documentation of the module and processor, including user's guidance

< supply mathematical formulations and documentation of requirements, design, specifications, and testing.

FRAMES-HWIR Technology Software System Team Members

Government Agencies
EPA--Office of Solid Waste
EPA--Office of Research and Development

Scientific Laboratories
Pacific Northwest National Laboratory

Expert Contractors
Research Triangle Institute
TetraTech, Inc.
HydroGeologic, Inc.

In the area of testing, module and processor developers were expected to

- develop a test plan
- ensure that testing of programs before they entered the system was thorough and well documented
- ensure that their components communicate with the wider system through a number of shared routines and document such system tests
- revise requirements documentation, design/specifications documentation, and program code implementation as needed to resolve issues found during testing
- document computational module and processor limitations and address those limitations, as needed in coding, to ensure that the program functions as intended and to eliminate those limitations that inhibit the required functionality of the software
- provide documentation from internal testers to support the conclusion that software meets its requirements
- undergo a system-wide verification test in which all modules or processors run through two example assessments to ensure that the same results are produced consistently across components.

Fourth, each component of the system, as well as the overall system, was tested by someone other than the developer to ensure that it would function as intended.

Fifth, all data entering the system went through a quality assurance process. In addition, all data have acceptable ranges, dimensions, and units associated with them, which are testable by the software system.

How Can I Learn More About the System?

The following documents contain additional information about the FRAMES-HWIR Technology Software System and its development. All documents are available through the EPA, Office of Research and Development, National Environmental Research Laboratory, Athens, Georgia.

Volume 1: Overview of the FRAMES-HWIR Technology Software System. 1999. PNNL-11914, Vol. 1, Pacific Northwest National Laboratory, Richland, Washington.

Volume 2: System User Interface Documentation. 1999. PNNL-11914, Vol. 2, Pacific Northwest National Laboratory, Richland, Washington.

Volume 3: Distribution Statistics Processor Documentation. 1999. TetraTech, Lafayette, California.

Volume 4: Site Definition Processor Documentation. 1999. PNNL-11914, Vol. 4, Pacific Northwest National Laboratory, Richland, Washington.

Volume 5: Computational Optimization Processor Documentation. 1999. TetraTech, Lafayette, California.

Volume 6: Multimedia Multipathway Simulation Processor Documentation. 1999. PNNL-11914, Vol. 6, Pacific Northwest National Laboratory, Richland, Washington.

Volume 7: Exit Level Processor Documentation. 1999. PNNL-11914, Vol. 7, Pacific Northwest National Laboratory, Richland, Washington.

Volume 8: Specifications. 1999. PNNL-11914, Vol. 8, Pacific Northwest National Laboratory, Richland, Washington.

Volume 9: Software Development and Testing Strategies. 1998. PNNL-11914, Vol. 9, Pacific Northwest National Laboratory, Richland, Washington.

Volume 10: Facilitating Dynamic Link Libraries. 1999. PNNL-11914, Vol. 10, Pacific Northwest National Laboratory, Richland, Washington.

Volume 11: User's Guidance. 1999. PNNL-11914, Vol. 11, Pacific Northwest National Laboratory, Richland, Washington.

Volume 12: Dictionary. 1999. PNNL-11914, Vol. 12, Pacific Northwest National Laboratory, Richland, Washington.

Volume 13: Chemical Properties Processor Documentation. 1999. PNNL-11914, Vol. 13, Pacific Northwest National Laboratory, Richland, Washington.

Volume 14: Site Layout Processor Documentation. 1999. PNNL-11914, Vol. 14, Pacific Northwest National Laboratory, Richland, Washington.

Volume 15: Risk Visualization Tool Documentation. 1999. PNNL-11914, Vol. 15, Pacific Northwest National Laboratory, Richland, Washington.

Quality Assurance Program Document

Gelston, G. M., R. E. Lundgren, J. P. McDonald, and B. L. Hoopes. 1998. *An Approach to Ensuring Quality in Environmental Software*. PNNL-11880, Pacific Northwest National Laboratory, Richland, Washington.

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Office of Civilian Radioactive Waste Management (OCRWM). 1995. *Quality Assurance Requirements and Description, Supplement I, Software*. U.S. Department of Energy, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1997. *System Design and Development Guidance*. EPA Directive Number 2182, Washington, D.C.

Whelan, G., K. J. Castleton, J. W. Buck, G. M. Gelston, B. L. Hoopes, M. A. Pelton, D. L. Strenge, and R. N. Kickert. 1997. *Concepts of a Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES)*. PNNL-11748, Pacific Northwest National Laboratory, Richland, Washington.

What Do These Terms Mean?

database a collection of data, generated external to the FRAMES-HWIR Technology Software System, arranged for ease of retrieval by various computer programs

data file a collection of data generated by the FRAMES-HWIR Technology Software System arranged for ease of retrieval by various computer programs

design *noun*: comprehensive description of how a piece of software will function (that is, how it will meet its requirements); hence, a design document includes such a description
verb: to identify how a piece of software will function and meet its requirements; hence, we design a piece of software by writing down the description. In either case for the FRAMES-HWIR Technology Software System, design includes short-term as well as longer-term capabilities of the software.

development the process of programming to meet user requirements as specified in the software design

FRAMES-HWIR Technology Software System name of the technology being developed to automate EPA's HWIR Assessment Strategy; FRAMES in this context stands for Framework for Risk Analysis in Multimedia Environmental Systems and is a software system developed by the Pacific Northwest National Laboratory for the U.S. Department of Energy and the U.S. Environmental Protection Agency.

input/output specifications detailed descriptions of data and their format necessary to allow processors and modules within processors to transfer information effectively with each other

limitation a characteristic of a given model that bounds how results are estimated, provided, or interpreted

location the geographic reference point for a site in latitude/longitude coordinates

mixed waste nonhazardous chemicals mixed with hazardous chemicals to dilute the hazardous chemicals for disposal, further treatment, or storage

model *noun*: scientifically based computer calculations that simulate physical or physiological phenomena
verb: to execute a set of scientifically based calculations to simulate physical or physiological phenomena

program a computer procedure for solving a problem, including collecting data, processing, and presenting results

requirements characteristics and behaviors that a piece of software must possess to function adequately for its intended purpose

shared routine computer program made available to other programs to use in conducting common tasks

site for the purposes of the HWIR assessment, an Industrial Subtitle D facility with one or more waste management units within a bounded area of approximately 20 km^2

specification detailed description of an interface to a computer program or set of subroutines such that another programmer could develop a program which would make proper use of the subroutines

test an activity designed to assess the quality of a component. As applied to documents, tests consist of critical reviews. As applied to software, tests are specific cases executed to verify a requirement or uncover an error.

test plan a detailed procedure for conducting a software test program. Test plans include a description of the component being tested, a summary of the requirements being tested, detailed descriptions of test cases, including the instructions necessary for conducting each test, and the expected results for each test to provide some criteria for deciding whether the test was successful

treated waste hazardous chemicals treated in some way to minimize their undesirable impacts

waste management unit a single source of contamination that could result in contaminant release to multiple environmental media; may include several of a single source type (for example, three aerated tanks in a grouping might be one waste management unit)

Abbreviations/Acronyms Used

DOE--U.S. Department of Energy
EPA--U.S. Environmental Protection Agency
FRAMES--Framework for Risk Analysis in Multimedia Environmental Systems
HWIR--Hazardous Waste Identification Rule
IBM--International Business Machines
MHz--megahertz
PNNL--Pacific Northwest National Laboratory
RAM--random access memory