

Light Water Reactor Sustainability Program

Fire Modeling Enhancement Tools and Methods



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Industry Fire Modeling Enhancement Tools and Methods

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ABSTRACT

Modeling and implementing fire safety for nuclear power plants is a costly activity. Because of the complexity of fire phenomena and multiple operational procedures, it is difficult to computationally provide assurance that mitigation methods are adequate for critical areas using current analysis methods. The nuclear industry needs an economical method to provide more accurate modeling and optimize mitigation methods to improve nuclear power plant understanding.

This report describes the background of current fire model strategy, the first stage of the development of a tool to help reduce resources needed in fire analysis, and the plan for the next step in advancing fire protection. The report lays out the path decided on by Idaho National Laboratory and industry representatives to best help reduce costs and improve realism in Fire Probabilistic Risk Analysis.

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ACRONYMS

API	Application Program Interface
CAFTA	Computer Aided Fault Tree Analysis
CFAST	Consolidated Fire and Smoke Transport Model
DLL	Dynamic Link Library
DOE	Department of Energy
EPRI	Electric Power Research Institute
FDS	Fire Dynamic Simulator
FRI3D	Fire Risk Investigation in 3D
GUI	Graphical User Interface
INL	Idaho National Laboratory
JSON	JavaScript Object Notation
NPP	Nuclear Power Plant
PDMS	Plant Data Model System
PRA	Probabilistic Risk Analysis
UI	User Interface

INDUSTRY FIRE MODELING ENHANCEMENT TOOLS AND METHODS

1. INTRODUCTION

The primary goal of this project is to develop affordable software for the nuclear industry that will provide realistic insights by reducing unreasonable conservatism in Probabilistic Risk Analysis (PRA) models for the current nuclear operating fleet. This project will combine research goals from the Department of Energy (DOE) and Idaho National Laboratory (INL) alongside more practical aspects from Southern Nuclear to develop a tool that can improve the operations, maintenance, and realism of the fire PRA. This software, Fire Risk Investigation in 3D (FRI3D), will provide immediate benefits to facility operations in performing fire analysis and updates. Long term, this software's application program interface (API) will provide the back end for advanced time-dependent fire analysis.

2. Nuclear Power Plant Fire Modeling

Nuclear power plants (NPPs) are currently asked to incorporate some level of risk-informed PRA methodology to assess fire risk to the reactor. A large resource effort is used to develop and then maintain these fire models and, due to a variety of limitations, there are a considerable number of conservative assumptions that are currently used within the models. The purpose of this research is to first improve the tools and their user-friendliness to quickly model, design, and assess a fire PRA, then reduce the conservatism of some of the more significant areas to help improve both the realism and the insights from these fire PRAs.

2.1 Industry Tools & Data

2.1.1 FRANX & CAFTA

The two most common software packages used when creating a fire PRA are FRANX and computer aided fault tree analysis (CAFTA). FRANX is software developed by Electric Power Research Institute (EPRI). It uses a Microsoft Access database to help generate fire scenarios using plant and component information, linking failure events modeled within the PRA to specific components, associated cables, and other information. It allows for specific initiators to damage specific targets so the program can identify failure modes, and which targets to include or exclude in the scenario analysis. CAFTA is software used to develop fault trees that model the PRA credited systems, components, and actions used to mitigate initiating events that lead to a plant trip. It also allows for the quantification of fault trees to find measurable results for the likelihood of accidents and the drivers of risk. FRANX can quantify the models as well, but it is typically used only for fire or flood accidents. CAFTA is used for all types of initiators.

2.1.2 Plant Data Model System

Each plant has some sort of database that tracks relevant components, equipment, cables, cable raceways, and other plant data. A common methodology is called plant data model system (PDMS) The level of detail and amount of information that this database contains will vary, but it is used to gather component and cable links, location data, drawing, and document information, etc. Although most plants implement a similar design, PDMS's vary in each NPP in the amount of data, table content, and reference methods.

2.2 Modeling Challenges

2.2.1 User Limitations

One of the difficulties is that there is a considerable amount of effort required to create the fire PRA. First, all sources of fire possible within the plant must be characterized, located, and the severity of the potential fire determined. From there, all PRA components that are required to perform “safe shut down” of the plant must be identified and modeled. Once all PRA components are identified, the associated cables must be tracked down to provide information about the specific safety functions of each PRA component. Once the cables are identified, they must be traced through the plant. Once they have all of this information, users can break up the plant into specific fire scenarios, choosing a high level of detail to more accurately simulate the fire (for higher risk scenarios) or choosing more generic scenarios (for lower risk scenarios). This entire process takes time and requires multiple walk-downs to determine relationships between various components and equipment. Spatial relationships, if acquired, are limited and they are not contained within the model but as separate walk-down notes, which provide limited benefit for future work.

2.2.2 Modeling Limitations

Most zones of an NPP are conservatively modeled as full room burnup in order to minimize modeling effort. Only critical areas implement scenarios, varied component failures, and use physics-based fire simulations to determine failures. Any fire simulation analysis is done separately and then applied manually to the Boolean logic-based fire scenario model. Since the fire scenario model only contains the logical relationships, users cannot see where failure items are located, which would provide enhanced verification and reduce modeling errors. Additionally, any change requires new manual efforts to determine positioning and spatial effects.

There are some limitations found within a static PRA that prevent the use of properly timing how scenarios develop when dealing with a fire. Since fires generally take time to build up, there will be a variable time in which things fail, or events occur. When dealing with a static PRA, things cascade immediately (the model is simply Boolean logic-based). Using the FRI3D software, we can get better insights into how the actual timing occurs within the scenarios and either use the models to get a more realistic quantitative value for each scenario, or to improve the static PRA so it more accurately models how scenarios play out.

3. Fire Risk Investigation in 3D

The FRI3D software consists of two main parts: the API backend with the logical fire model, and the graphical program interface with a 3D viewing front end. This combination allows users to develop and see spatial relationships, along with existing fire models. This section will go over communication and capabilities of these pieces.

3.1 Data Processing Backend

The data processing side of the application is written in C#. This method was chosen because of the multiple packages available for accessing different data structures, ease of development, and long-term maintainability. There are several projects that use shared libraries and packages to accomplish all the data processing.

In order to be cost-effective for facilities, this tool must integrate with the existing plant databases and fire models. Although not all facilities use the same software, most do use the EPRI software called FRANX for performing fire analysis [1]. However, FRANX is focused on only the logical relationship used in fire modeling and does not have location information, which is maintained by a plant model. The software or database structure used can vary between facilities.

The most common data format for plant data is PDMS. The beta version of FRI3D integrates with both FRANX and PDMS, however the data integration for the plant model is done through a module that can be easily customized for other systems. Figure 1 shows the separation between the API and the Graphical User Interface (GUI) and the integration with FRANX and PDMS. An internal database using SQLite is used to store all the 3D information from the GUI, the fire model logic from FRANX, and the plant info from PDMS [2]. Information is exchanged using the JavaScript Object Notation (JSON) approach to data-interchange.

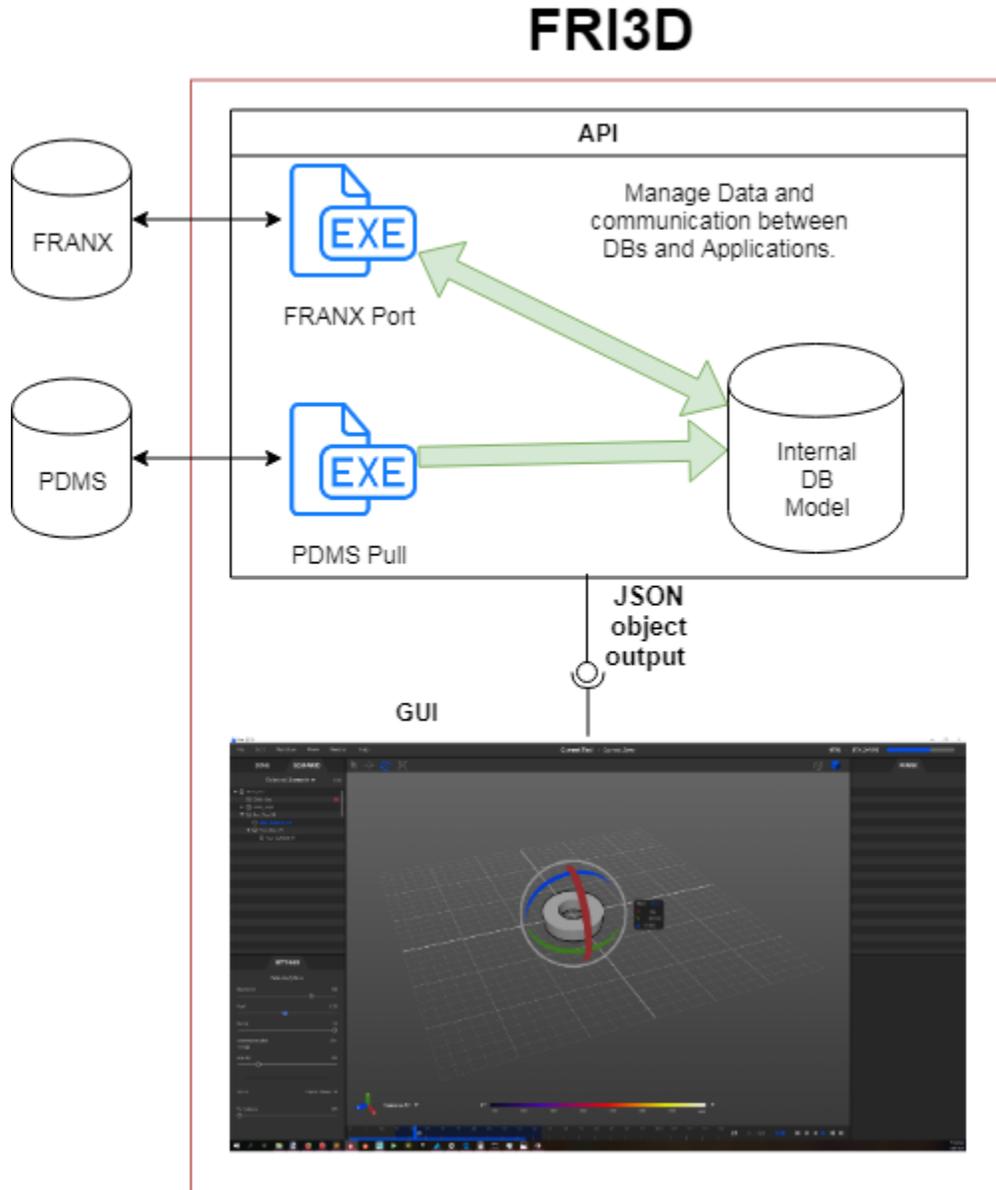


Figure 1. The different components and integration for the FRI3D software.

3.1.1 FRANX Data integration

The FRANX database stores the relationship between the following items of the nuclear facility in a tree-like structure.

- Zone – The physical area of a facility is divided into logical fire zones.

- Raceways – Varying types of equipment that carry cables from one location to another.
- Cables – Wiring that runs from either a power source or controller to another piece of equipment.
- Component – A physical component in the facility that can be affected by fire directly or through the failure of a connected cable.
- Basic Event – Failure modes for a component. These reference a basic event in the PRA for calculation purposes.
- Scenarios – These consist of an ignition source and determine what items in the zone will fail.

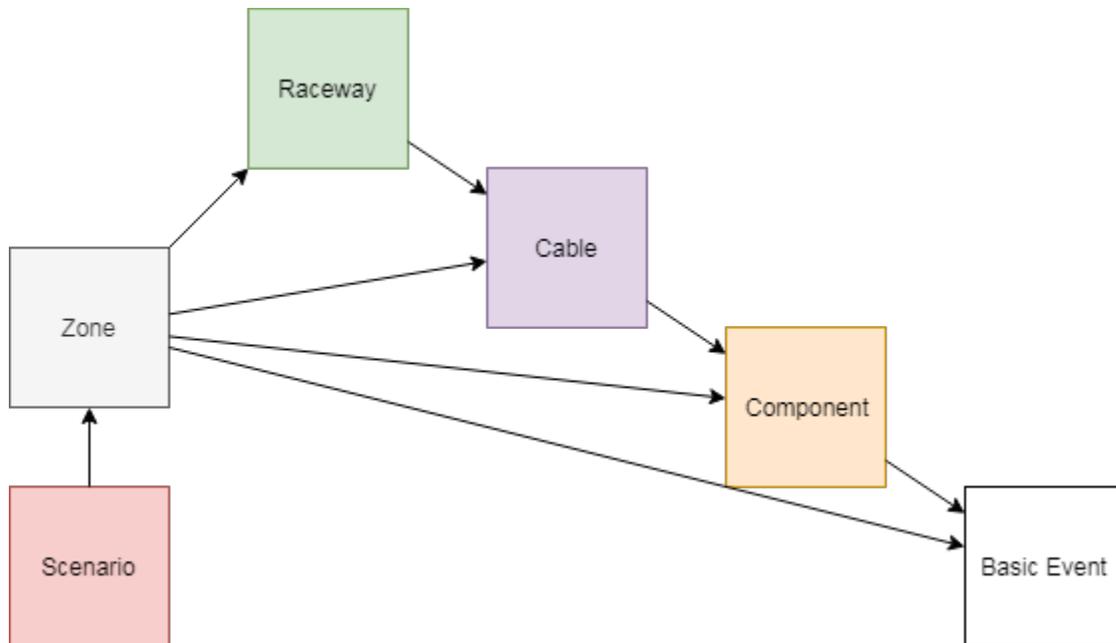


Figure 2. Relationship between fire model items.

A Microsoft Access database used for this data storage and was designed for readability and manipulation by humans. Relationships between different elements such as what cables are in a raceway are done through a name comparison, without any keys or referential integrity. While this works for its intended purpose, the design is not suitable for fast lookups and other requirements for advanced analysis.

The unique information contained in the FRANX model are the scenarios. These scenarios define what things can happen in a zone and the effects of a scenario on the items in the zone. When running the FRANX model, failed items are propagated clear down to the basic event level where they are used to fail basic events in the PRA model for quantifying a result.

To use this data, as shown in Figure 1, an executable processes the FRANX database, retrieving all the items and saving them in our internal database structure. While some of the FRANX models represent a physical location relationship, such as zones, raceways, and cables, much of the data is logical only, meaning that if this item fails, then all the child items also fail. For example, a cable may have wires for many sensors located in various locations, and if that cable is burned, those sensors may fail in different ways. FRI3D needs to maintain this relationship but separate it from the physical location relationship.

3.1.2 PDMS Module

The PDMS includes components of locational relationships between facilities components and fire initiators. Because not all plants use PDMS, a module approach is taken to import the data. An interface

defines the required procedures to be implemented. If a facility uses a different data storage method, or has a different naming structure, only a small piece of custom code needs to be developed. As shown in Figure 3, facilities would replace the “Vogtle PDMS” node with custom versions.

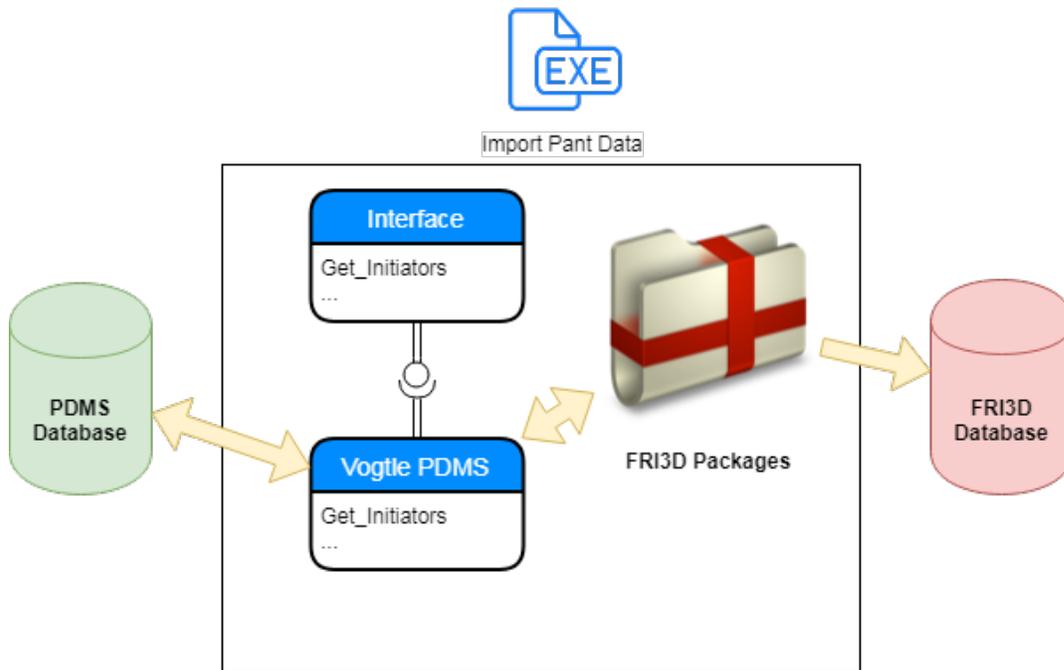


Figure 3. Modular design for importing plant data.

3.1.3 Data Indexing

As data is pulled from FRANX and the plant database, all description string values are indexed using Lucene [3]. This indexing allows for quick searching by the code or user, similar to how Google is able to search for relevant websites. This method not only allows FRI3D to match known items by name, it can also make logical assumptions in relationships, such as references to initiators in the scenario description. While these assumptions may not be 100% accurate, they provide the user a good base and have no effect on quantifications without further adjustment and modeling by the user.

An additional planned feature will soon allow the user to index plant-related documents. This will allow users to find other references for a component and bring up those references. This will speed up research time when reviewing a scenario or making model changes.

3.1.4 Application Program Interface

All communication between the user interface (UI) and the data processing back end is handled through a Dynamic Link Library (DLL) API. This is for two reasons: first, the 3D UI required a different programming language (C++) for development, so a DLL API was chosen for communication. Second, future development in advanced fire modeling required the decoupling of the UI from data processing so it could be used with other tools.

Calls requiring data structures are passed through as JSON strings. JSON is a common data-exchange format with libraries in every standard language [4].

3.2 3D User Interface

The user interface is designed to build and show the link between the fire logical model and physical relationships. This is done by breaking up the data into three areas: the FRANX model on the right, the 3D model in the middle, and the physical zone items on the left as seen in Figure 4.

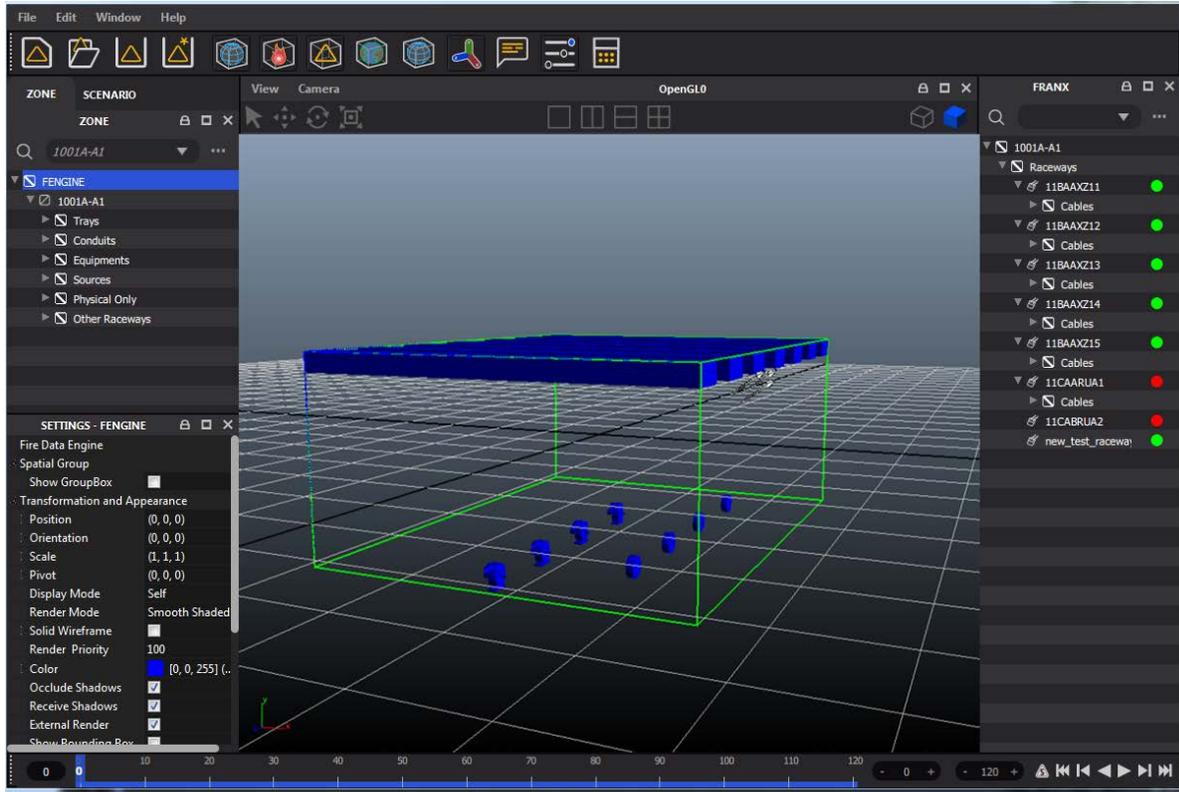


Figure 4. FRI3D GUI for developing and modifying scenarios.

To begin, users open the FRI3D model and then load either the desired zone or scenario using the “...” button. If they load a zone, any scenarios associated with that zone are shown in a dropdown, allowing them to quickly see and switch between different scenarios. If users load a scenario, all (if more than one) zones affected by that scenario are listed in the zone dropdown. The FRANX model for the loaded zone is loaded into the right-side tree view.

3.2.1 3D Modeling Area

The 3D area allows users to model the area and items in the current zone. Users can drag and drop items from the zone list into the 3D area and a default item is created. From here they can move, rotate, or resize the items through control buttons at the top of the section, as shown in Figure 5. This allows quick modeling of the zone given plant designs or walk-down notes. Custom models can also be imported for each item if basic shapes are not desired.



Figure 5. 3D view manipulation tool bar for moving, rotation, resize, camera view, etc.

This interface also allows users to quickly see what items in the zone are affected by the current scenario by greying out items that fail for that scenario, as shown in Figure 6. When users select an item, it is highlighted in any of the tree views referencing the item, such as the zone tree.

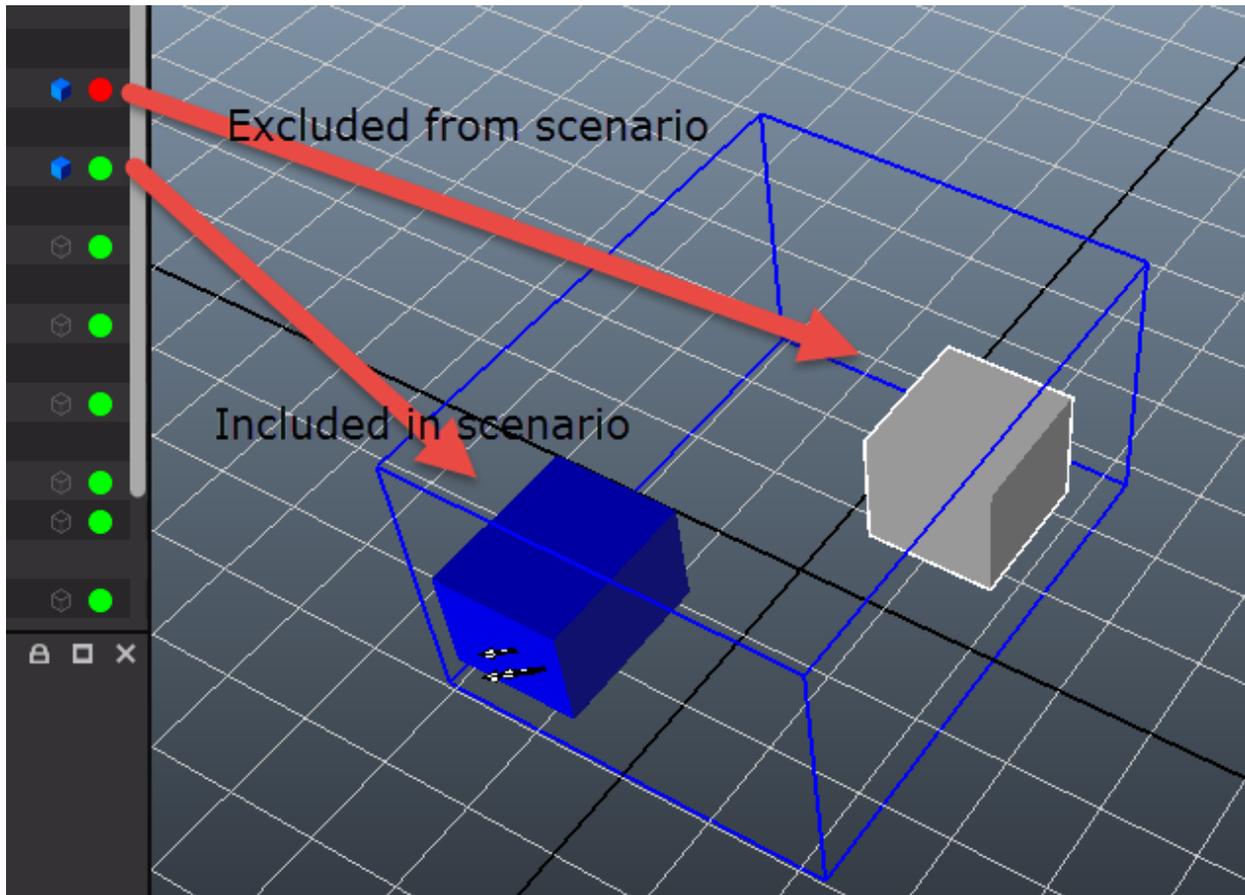


Figure 6. Items not included in the current scenario are greyed out.

3.2.2 Zone Tree View

Zones are displayed on a tab on the left-side of the screen. After users load a zone or a scenario, the first or default of the other is loaded. The dropdown box lists the current zone and the arrow option lists all the zones affected by the current scenario. Users can change the zones in two ways, by either selecting a different zone in the dropdown (if more than one exists for the scenario) or by clicking on the “...” next to the dropdown list. The “...” option brings up a list of all the zones in the model. Loading a new zone will also close the current scenario and load the first scenario associated with the zone.

Categories of items listed in the zone can depend on the facility’s PDMS. For this beta version, developed off of Southern Nuclear Companies’ Vogtle model, there are “Trays,” “Conduits,” “Other Raceways,” “Cables,” “Sources,” and “Physical Only” items.

- Trays – A type of raceway in FRANX containing cables.
- Conduits – Another type of raceway in FRANX, typically containing one cable and a more flexible routing property.
- Other Raceways – Items like junction boxes or other items that cables pass through that are not trays or conduits.

- Cables – Power and signal lines in the facility; the only item not modeled in the 3D interface directly, they belong to trays, conduits, or unknown raceways.
- Sources – Special components inside the zone area that can cause a fire in the zone.
- Physical Only – Items identified in the PDMS or added by the user that are physically in the zone but are not part of the FRANX model. These items may contribute to the simulation only if they are used in a physics model such as Consolidated Fire and Smoke Transport Model (CFAST) or Fire Dynamics Simulation (FDS) model.

Icons next to items in the Zone tree view show if the object has a 3D model associated with it and if the item is used in the current scenario, as show in Figure 7. Users can drag and drop from this list into the 3D display to create a 3D model for the object. Selecting an item that has a 3D object will highlight that item in the 3D display. Users can right-click on items for a menu of options, such selecting an excluded item and including it in the current scenario.



Figure 7. Icons what the icons mean in the zone tree.

3.2.3 Scenario Tree View

Scenarios are displayed on a tab on the left side of the screen. After users load a zone or a scenario, the first or default of the other is loaded. The dropdown box shows the name of the current scenario and the arrow option lists all the scenarios associated with the current zone. Users can change the scenario in two ways, by either selecting a different scenario in the dropdown (if more than one exists for the zone) or clicking on the “...” next to the dropdown list. The “...” option brings up a list of all the scenarios in the model. Loading a new scenario will also close the current zone and load the main zone associated with the new scenario.

Categories of items listed in the scenario are a subset of items listed in the zone plus any items from other secondary zones that fail due to the scenario.

Icons next to items in the scenario tree view show if the object has a 3D model with which it is associated and if the item is from the current zone. Users can right-click on items for a menu to exclude the item from the current scenario.

3.2.4 FRANX Tree

The tree view on the right side allows users to view the logical representation or the FRANX model. This still allows them to perform actions on items that are related to failures in the physical area. For

example, excluding a component in a different area that is also tied to a cable failing in the current zone. The same exclusion rules apply to this area, as is done in FRANX.

3.2.5 Generating Results

3.2.5.1 Excluding items

There are two ways to exclude an item from a scenario. Both the Zone tree view on the left and the FRANX tree view on the right allow users to exclude items. However, these have a different behavior.

Excluding an item from the left-side tree items, or the physical items, means it does not fail in any manner due to the fire. For example, if you exclude a piece of equipment, it will not fail no matter how many failures occur in cables or other items related to that piece of equipment. This allows users to easily develop “What If” scenarios.

In the FRANX tree view, excluding an item only removes the failure from a specific path. For example, if users trace a component down a cable and exclude it, the component will not fail from that cable failure. However, if a different cable fails, that is, the cable also connects to that component, then the component will still fail. This is the normal behavior for excluding items in FRANX, allowing users to fine-tune a scenario.

3.2.5.2 Quantification in FRANX

After users make changes to the scenario by excluding or including items, they can generate a FRANX model for quantification through the “Calculate” menu button shown in Figure 8. Users are then prompted through a file browser to select a FRANX model as a base to generate an updated model with the modified scenario. The new model is then automatically opened with FRANX, and the software is ready to solve the current scenario. (A licensed copy of the FRANX software must be installed with the “.franx” file extension associated with the application.) Quantification and other analysis from this point is done using standard industry software.

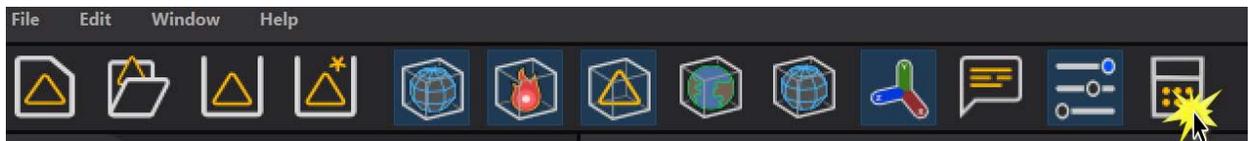


Figure 8. Top menu buttons (calculate indicated by the mouse click image).

3.3 Further Work

This stage of the development verified the ability to import industry model data and add data with a 3D design interface. As a milestone, it helped verify the technology, providing a continuation decision point. However, to be useful for industry, a few critical aspects must be added.

3.3.1 Incorporating Fire Simulation

Currently codes such as FDS and CFAST are developed independently for specific scenarios and the results are then transferred to the FRANX model. Having 3D models with zones allows auto-generation of a physics-based model. The first step will be generating a CFAST model as it is more commonly used by industry and has simpler requirements. After solving the CFAST model, the user can import the results to automatically generate the scenario failures. This will eliminate time used for building CFAST models, time for translating the results to the PRA model, and any manual processing errors.

3.3.1 Simulation Visualization

Once a supported fire simulation code has been executed and imported, the results will be shown in two ways. First, all the components will be marked with the red and green indication marker. Second, the timeline at the bottom of the display will show dots when each item fails. Users will be able to select any

point on the timeline and all the items that have failed up to that time will be highlighted in the 3D area. Additional work will allow for the visualization of the fire and smoke directly in the 3D area.

3.3.2 Advanced Fire Modeling

Once physics-based fire simulation tools have been incorporated, the next phase of development will include advanced methods to add critical timing aspects and operator actions, such as manual suppression. The current plan is to develop a model of the switch gear room of our industry partner's plant using the FRI3D UI. The switch gear room contains several critical scenarios that are likely to show benefits using advanced modeling methods.

3.4 Cost Savings

By using the FRI3D software for day-to-day operations and adding 3D modeling as needed, facilities will be able to see performance improvements without a huge up-front modeling effort. The software is designed to make modeling efficient, but it will still require effort so it should be done on an as-needed basis. As time progresses and modeling completed of the most commonly used areas, the modeling effort will be negligible. A cost evaluation and savings estimate will be developed with our pilot plant with the use beta testing of the FRI3D software. We anticipate this tool will provide a cost savings in these areas.

3.4.1 Walk Downs

Walk downs are performed when the location of an item is unknown, or evaluation of an area is needed. Often this is required because blueprints, pictures, or previous walk down notes do not contain the data or enough detail required. Walk downs are typically done on an as needed basis, by completely modeling the entire room at the onset, it would remove the need for redundant additional costs besides the actual walk down time, including travel, paperwork, and access availability. If the company has several NPPs they may collocate PRA modelers near one facility or in a central location, so travel costs can prohibit quick or frequent walk downs. Given these constraints, they try to perform several walk downs in one visit, which can also reduce turnaround time. By adding a zone's 3D model in FRI3D the need for additional walk downs should be eliminated except for rare circumstances.

3.4.2 Operations Request

Plant operations makes requests to the PRA group for maintenance and configurations when issues arise in the NPP. If any failed components or maintenance plans can affect the fire risk, then those changes must be evaluated. Sometimes these requests are simple only needing a small change and quantification of the model, but often they require in-depth review and lookup of diagrams or a walk down. FRI3D will allow the user to make both the simple modifications, assist in the lookup references, and likely eliminate the need for a walk down. An estimate from industry was given from a day to up to a couple weeks.

3.4.3 Plant Modifications

When NPPs plan plant modifications they must run all designs through fire analysis. Additions or changes to equipment can be a source of new fire sources or fire scenarios and cables to the equipment become targets for existing fire scenarios. Experience has shown that the placement of both the equipment and cables can be critical for fire analysis results. Adding new equipment and making modifications to a zone already modeled in FRI3D will make this a simple process, a few hours to a day for turn around. This can typically take from a couple days to a couple weeks depending on if the modification is in a simple full room burnup area or a critical area that needs a fire simulation, such as CFAST, to be run or entirely new scenarios developed.

3.4.4 Regulatory Risk

Another cost to NPPs is from fines or avoiding of fines from regulation. This expense can be reduced by lowering the conservatisms in the fire PRA models, creating a more realistic model. Then if an event occurs the model can more accurately assess the risk of the event where a conservative model may lead to a high risk estimate. Alternatively, analysis can be performed after the event to better understand the risk of the event, and if the plant can show the risk was lower than what was previously thought, the plant may avoid unnecessary regulatory complications.

4. References

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