Meeting Regulatory Requirements for Fire Safety Assessments with the PB FANS Software System

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Abstract

Fire safety assessments (FSA) for nuclear facilities require the completion of a code compliance review, a fire hazard assessment and, in the case of facilities with a reactor, a fire safe shutdown assessment. The regulator requires that the assessments reflect the plant configuration and demonstrate that the impact of fire on safety objectives has been considered. Completion of the FSAs requires a large quantity of information on the facility. This article presents how database type software can be used to store data summarizing the arrangement of fire hazards, safety systems and protection features. With this data, and spatial arrangements defined, assessments can be performed, evaluation results entered and reports generated to provide comprehensive documentation of the assessment results. Also, once an original assessment is performed the costs of maintaining and updating of assessments becomes a manageable and cost effective means for reporting regulatory compliance.

1. Introduction

Fire safety assessments are a licensing requirement for nuclear facilities. Current regulations are trending toward performance based approaches for demonstrating compliance. This trend has prompted the development of PB FANS – Performance Based Fire Analysis for Nuclear Safety, as a software system for retaining the large amounts of facility data, recording the various assessments performed and reporting results.

This software system provides nuclear facility operators, management and regulators with the necessary tools and datasets to meet regulatory requirements with respect to fire hazard assessment (FHA), fire safe shutdown assessment (FSSA) and code compliance reviews (CCR)

2. PB FANS Context

PB FANS software was developed to support fire safety assessments both from the fire safety analyst's perspective and that of the nuclear safety specialist, plant management decision maker and regulator. The primary objective of the software is to provide the tools, configuration management and utilities to assess the nuclear facility's adequacy to meet safety objectives and regulatory requirements. With this objective in mind, PB FANS was designed as a set of modules including libraries, data tables, a query module, a report generator, the System Interdependency Model (SIM) and a capture interface for the import of fire scenario consequence modelling results.

The main libraries are comprised of combustible materials, nuclear safety equipment, building construction material references, fire protection system data, codes and standards references and assessment results in terms of deviations and related recommendations.

2.1 PB FANS Architecture

As a web-based application, PB FANS permits remote, multiple user access along with the appropriate security protection features. The general software architecture is a three-tiered application with the presentation layer accessed through the web browser, the application layer servicing user queries as well as updates to the database fields and the third layer for data storage services. The PB FANS structural organization is shown in Figure 1.

The model view controller (MVC) hosts the user interface and generates action modes in response to user requests: (a) indexing – to generate a list of similar data items, (b) create – a new data item, (c) view – present a data item in read only format, (d) edit – update field values and (e) delete – suppress a data item

2.2 Main Data Tables – Capturing & controlling station data

Data tables have been built to record physical site data, fire hazards and controls, available protection features, nuclear safety equipment, cables and cable raceways as well as for logging radioactive materials.

CATEGORY	DATA TABLES
Physical Data	Buildings, Rooms, Room Barriers, Adjacent Rooms
Fire Hazards	Combustibles, Ignition Sources (Fixed & Transient)
Hazard Control	Ventilation, Drainage, Spill Control
Fire Protection Features	Detectors, Suppression, Extinguishers, Hoses, Barriers, Spatial Separation, Special Protection Features
Nuclear Safety	Nuclear Safety Systems, Equipment, Cables, Cable Raceways
Radioactive Materials	Radioactive Materials

Table 1. PB FANS Main Data Tables

The physical data comprises building information including occupancy classifications (as per the National Building Code of Canada, NFPA and site building designations), construction type, room definition including dimensional data, barrier construction & dimensions including openings and their protection status.

PB FANS contains fire hazards in the form of combustible materials data including combustible mass, energy content and fire growth rate. Ignition source data is also tracked by equipment type, source type and temperature as are hazard controls such as ventilation, drainage and spill control.

Fire protection features as listed in Table 1 are all captured in the PB FANS database. Fire protection system design criteria are also recorded to assess protection adequacy for the room hazard under consideration.

Nuclear safety system descriptions and data relationships are described in section 3.2 – nuclear safety components, cabling and logic.

Radioactive and hazardous material data is entered into specific fields covering the material type, the radiation hazard, quantity information, source strength and reference information.

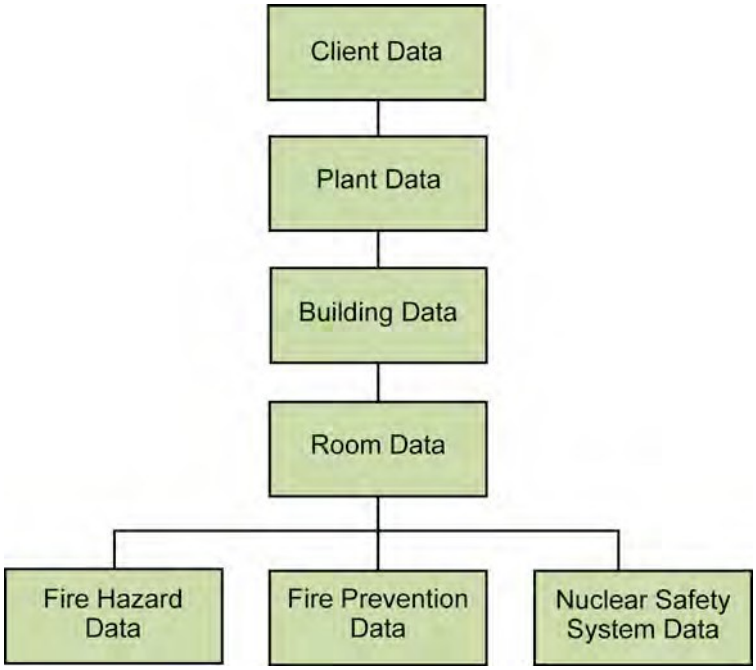


Figure 1. **PB FANS Structural Organization**

3. Station Configuration and Database for CCR/FHA/FSSA

PB FANS software accommodates the facility's configuration control and the significant number of facility systems, subsystems and components needed to execute and update Fire Safety Assessments. The various libraries organize key information, standards, look-up tables and fire protection system data. Nuclear safety system (NSS) configuration, cabling and relationships support the system interdependency model (SIM) and its role in confirming safe shutdown capability.

The structured query language functionality is important as it enables filtering, sorting, listing and summarizing of facility information by location to support fire safety assessment tasks.

3.1 PB FANS Libraries

PB FANS libraries have been implemented to record station configuration data and facilitate user lookup and tracking.

LIBRARY	DATA DETAILS
Combustible Materials	Heat of Combustion, Growth Rate, etc.
Nuclear Safety Equipment	Damage Limit for equipment & cables to temperature, heat flux, smoke density, water, etc.
Wall and floor constructions	Thermal/physical properties of construction material
Fire Detection	Detector type, temperature rating, RTI
Fire Extinguisher	Size, rating
Reference Standards	Regulatory documents, codes and standards
Common Deviations	Deviation, code references, technical resolutions
Common Recommendations	Recommendation, priority, status

Table 2. PB FANS Libraries

3.2 Nuclear safety components, cabling and logic

To assess whether a facility is capable of achieving and maintaining a reactor in subcritical condition in the event of a fire, nuclear safety system (NSS) equipment, cabling and logic must be gathered and configured in PB FANs. Safety data that conforms to industry guidelines [Ref. 5] can be readily imported and other data configurations can be accommodated. All nuclear safety equipment and cables are linked to rooms in the database to permit identification of impacts based on special arrangement. All NSS logic relationships are also identified as well as their contribution to achieving the safety performance criteria of CSA N293-07;

- Reactor shutdown
- Decay heat removal
- Plant monitoring systems
- Barrier to fission products
- Supporting functions (power, water, air and other support functions)

To support fire safety assessments, it is clear that PB FANS must retain, sort and manipulate a large volume of facility information. The software system screens facility information according to room designations, with the focus on NSS equipment, cabling and logic. Success paths to safety performance objectives can be queried with the SIM to graphically show safe shutdown can be achieved. Failure paths can be similarly displayed.

3.3 SIM

The heart of the fire safe shutdown assessments is the System Interdependency Model (SIM) which interrogates the facility's nuclear safety logic with the objective of confirming safe shutdown capability. The SIM is hierarchical and is constructed from the plant logic. The safety logic in achieving each of the safety performance criteria are displayed in tree form:

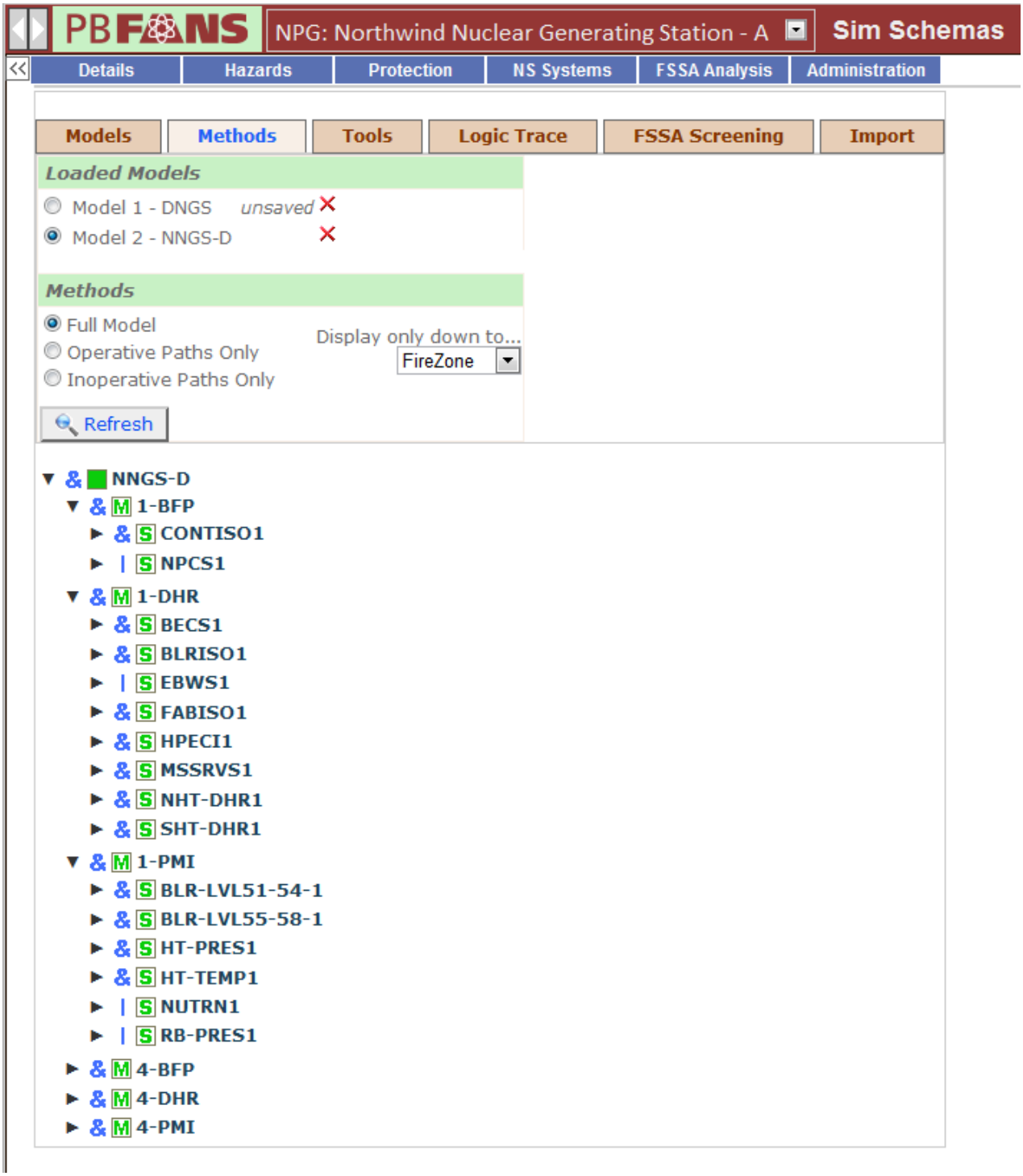


Figure 2. SIM Display for Performance Criteria

This device dependency logic is encapsulated in Boolean dependency relationships. SIM is constructed as a top down tree with the Fire Safe Shutdown performance criteria (Methods) at the top and all systems, subsystems, devices, cable trays and cables descending from the methods, interconnected by nodes. All devices and cable trays have a spatial identification.

The SIM tree display uses a number of different icons, symbols and color codes to convey the information contained in the model. A green colored icon indicates an operational, enabled node, while a red icon indicates a disabled or non-operational node.

Node icons identify the type of node they represent by a single character or symbol:

SIM Tree Node Symbols

Node Type	Operational	Non-operational
Method nodes	M	M
System nodes	S	S
Device or Equipment nodes	D	D
Cable nodes	C	C
Room nodes	R	R
Logical group nodes	✓	✗

Table 3. SIM Tree Node Symbols

SIM features can be accessed within PB FANS including (a) tools for model building, toggling states, and model updating, (b) methods for controlling the display of the model, (c) the trace logic function and (d) the FSSA screening function.

3.4 PB FANS Performance Features

Some of the highlights of PB FANS performance features include:

- Storage, management, and retrieval of large amounts of data
- Search, sort, and data verification
- Efficiency in updating existing data and entering new data
- Performance of specific calculations based on the data
- Capture of technical evaluation results required by the safety regulations
- Management of specific queries and generation of report results for regulatory review

- Integration with PSA (Probabilistic Safety Assessment)

The main attributes of the User Interface (UI) include the below-referenced forms, controls, dialog boxes, navigation panes, menu bars and dropdowns:

- All the pages or forms for creating, displaying and updating application data have a static Action and Control Button Bar at the bottom of the application window.

- Validation controls are attached to most of the forms and when data is saved, it is analysed to ensure that it conforms to the data validation criteria for the specific form. An error dialog is presented to inform the user if any of the data validation criteria fail.

- A Delete Confirmation dialog box is presented to prevent the accidental deletion of data items.

- The User Interface layout is designed so that the navigation pane appears on the left and the form pane is displayed on the right side of the Web page. The navigation pane is collapsible to conserve viewing space and increase productivity.

- Menu Bars, Drop Down Menu Windows, Pop Ups, etc. are featured for the PB FANS user to perform the operations of displaying and updating application data.

4. Fire Safety Assessment Processes and PB FANS

PB FANS is designed to capture fire safety assessments performed. Fire safety assessment processes documented and reported by the software include:

1. Screening assessments
2. Fire scenarios evaluations
3. Fire scenario results in terms of impacts
4. Identification of unacceptable consequences
5. Evaluation of fire protection system adequacy
6. Resolution of unacceptable consequences

Screening assessments are straight forward sorts of the database to identify and report rooms meeting specific criteria (e.g. nuclear safety equipment or cables, radioactive materials, etc). These assessments can be tailored to meet a specific assessment methodology and are the starting point for identifying rooms requiring more detailed assessment.

4.1 Fire Scenarios Process

Rooms identified for more detailed fire assessment are generally subjected to a fire scenario assessment. These scenarios are initially defined independent of PB FANS and are later captured so that the software system contains descriptions of each fire scenario.

Within PB FANS, fire scenarios descriptions are defined by the following attributes:

- Scenario Number – Assigned number based on room number and a sequential numeric identification.
- Scenario Source – Identifies the organization originating the scenario
- Classification – Identifies the status of the scenario relative to the assessments performed. (Active, Superseded, Screening, Multi-room, Test)
- Review Type – Identifies the type of fire assessments to which the scenario is applicable. (CCR, FHA, FSSA)
- Synopsis – Text field used to provide a summary of the fire scenario.
- Fire Location – Text field used to identify the location of the fire within the room.
- Calculation Method – The model used for the calculation (CFAST, ZOI, CFD, Other).
- Fire Duration – The time, in minutes, that the fire simulation is run.
- Fire Growth Rate – The t-squared fire growth rate used in the fire simulation.
- Fire Size – The maximum fire size used in the fire simulation.
- Target NSS – The nuclear safety equipment or cables in the room that could be damaged by the fire being evaluated.
- Target Other – For fire scenarios where NSS are not the target, the target should be defined in sufficient detail to determine potential for damage.
- Ventilation – Defines the ventilation conditions considered for the scenario.
- Assumptions – Text field to capture any scenario specific assumptions.

4.2 Fire Scenario Impact Assessment

Each fire scenario determines fire conditions in the room or environs of a postulated fire event. Conditions are defined in terms of temperature, smoke conditions, heat flux or other criterion. Based on the fire conditions and target vulnerability to damage, as defined in nuclear safety library, the impact of fire on nuclear safety equipment, cables or materials can be defined. This impact is summarized in PB FANS. This process is currently not automated so that the analyst must confirm the result.

In the case of fire impact to nuclear safety equipment and cables that are part of required fire safe shutdown systems the SIM may then be run to determine the consequences of damages on the ability to achieve safe shutdown. The SIM can be arranged to show failure or success paths for all performance criteria required for safety analysis. Failure of ability to achieve one or more performance criteria is an “Unacceptable Consequence” by the regulations. All unacceptable consequences can then be subjected to a resolution process.
PB FANS also contains a unique feature for evaluating adequacy of fire barriers. Given the low combustible loading in many areas and the large spaces of nuclear facilities the barrier evaluation

uses a Normalized Heat Load [ref 4] calculation to confirm the adequacy of a barrier. Changes in combustible loading can be readily evaluated to determine impact on the adequacy of a barrier.

4.3 Resolution process for unacceptable safety consequences

In cases where the fire scenario results in unacceptable safety consequences, a resolution process is enacted. This process was developed to include assessment requirements of Canadian standards but can be tailored to other needs or regulatory environments. The process consists of a four stage resolution process shown in Figure 3.

The first stage of the resolution process is a confirmation that a success path exists for all performance criteria. If a success path is demonstrated for achieving safe shutdown then no further assessment is required and consequences are confirmed as "acceptable". The second stage of resolution is to confirm that existing fire protection systems are credited and the fire impacts are reassessed. If fire scenario consequences are still unacceptable, the scenario conditions are reviewed for assumption conservatism or boundary condition issues. If consequences are still "unacceptable" the fire analyst refers the scenario to a nuclear safety analyst for Stage 3 resolution. For complete data sets meeting industry guidelines the SIM can be used to assess different failure modes or credit electrical circuit safety features. Nuclear safety system failure modes and event likelihood are reviewed as well as the additional nuclear safety systems that (a) are not part of the minimum set defined in PB FANS databases or (b) are well separated from the effects of the fire scenario. If these steps do not resolve the safety consequences, then under Stage 4 new fire protection options and their effectiveness are considered. Stage 4 should also include evaluations to confirm effectiveness of options selected to finally resolve the case.

Figure 3 – Unacceptable Consequence Resolution

4.4 Deviations from Fire Safety Requirements

Code compliance reviews and other assessments identify deviations from fire safety requirements. Where this occurs the deviation is summarized on a deviation form. The deviation form captures:

- Deviation description
- Location
- Review type initiating the deviation
- Fire safety category
- Code reference
- Standard reference (where applicable)
- Technical resolution
- Recommendation

The information collected defines the sufficient detail for sorting and reporting of items of interest. For each deviation a fire analyst must prepare a technical resolution. This resolution provides a description of the deviation and why it was initiated. Each technical resolution must also describe existing conditions and/or evaluations that support either no action or a recommendation for improvement. This feature of PB FANS allows tracking of minor as well as major deviation. All deviations are linked to a recommendation. Common recommendations link similar or common deviations such that recommendation reports for additional fire extinguishers will link to multiple deviations and the locations where they are needed.

4.5 Generating reports

Reports produced by PB FANS support the execution of fire safety evaluations or are generated to satisfy the requirements of the safety regulator. The types of reports that are pre-designed include,

- Building information
- Room data summaries
- Combustible loading summaries
- Automatic fire detection summaries
- Automatic fire suppression system summaries
- Fire extinguisher and fire hose locations and coverage
- Room barrier analysis
- Ignition source summaries
- Fire Safe Shutdown Systems equipment and cable fire impact
- Deviation summaries
- Recommendation summaries

5. Key Nuclear Station Operator Benefits

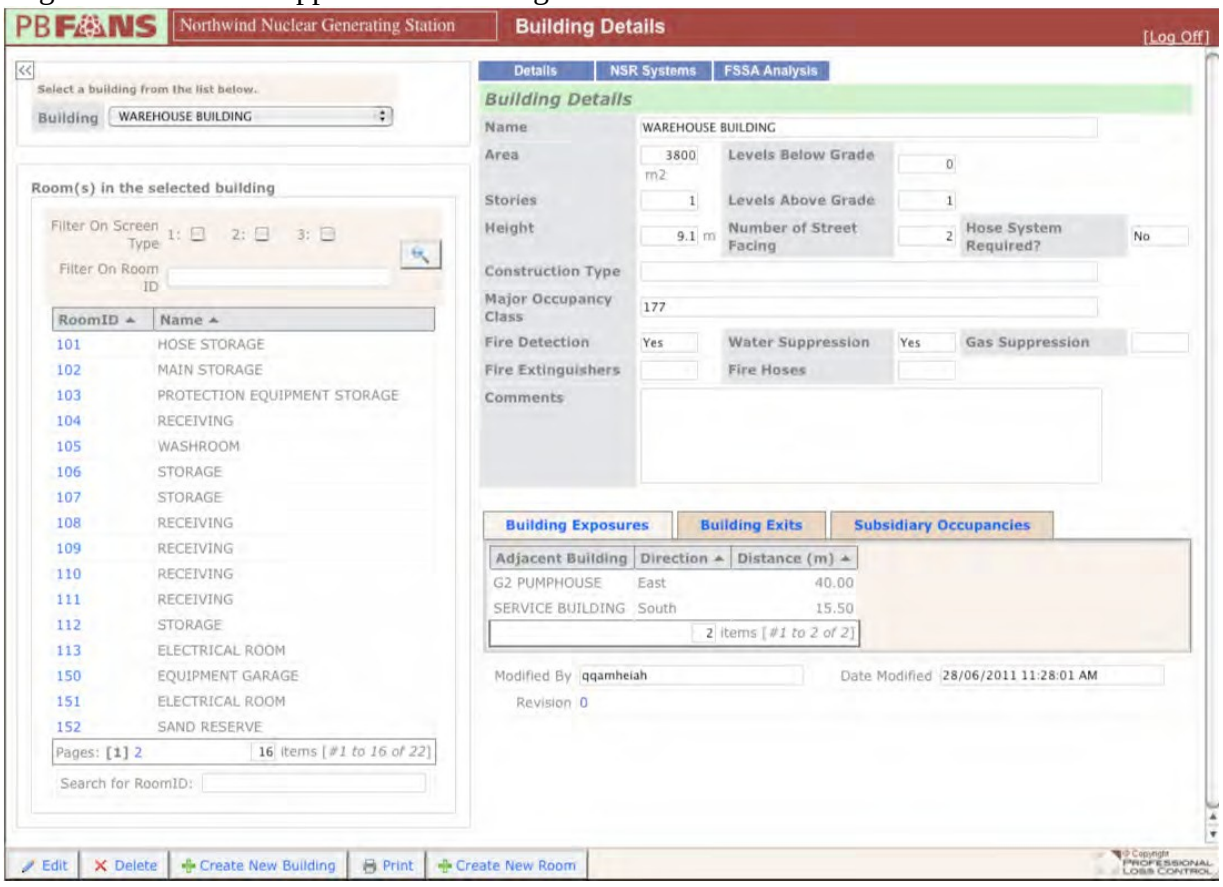
Fire safety assessments can take an extended period of time to complete and documentation can consist of literally thousands of pages of data and assessment results. The use of an accessible database provides numerous advantages to a nuclear facility owner in terms of real-time access, tracking of recommendations, evaluation of transient conditions and updating assessments.

5.1 Web based for real-time access

Once facility data has been entered and validated benefits are realized by real-time access. The fire assessment teams can work independently and enter the results of their work as completed. Process can be tracked by project management and when portions are complete they can be reviewed.

There are many benefits to facility operators of real-time access. The main advantage is being able to easily access the results of all assessments. Applications for work permits or storage of transient combustibles can also be handled within PB FANS. Identify the room and the nuclear safety systems present are immediately presented. What are the potential risks from change in conditions or fire hazards in the area? The assessment process can be followed and the safety impacts of a temporary condition, of modification, determined and if necessary resolved.

Figure 6: PB FANS Application Web Page Window



5.2 Recommendation tracking and status

Deviations that result in recommendation for facility improvements can be tracked in PB FANS. Recommendations can be tailored by setting priorities for action and for tracking the progress for completion. This permits easy follow-up and permits changes as needed. When a recommendation is completed and the improvement verified PB FANS can be updated and the locations where improvements would be realized would be identified. Update of improvements could prompt update assessment results. Since all changes in the system are archived an auditor or analyst updating the system can readily see changes within a given time frame and confirm the improvement in the next assessment.

Reports can also be tailored to report progress on recommendations for internal use or reporting to a regulator. If data is updated to reflect conditions in real-time then reporting of status is current and efficient.

5.3 Fire hazard analysis update efficiency

PB FANS has been designed to support fire safety assessments that need to be conducted at nuclear facilities. Technical personnel with specific training and experience deploy their knowledge and judgment in interpreting fire and nuclear safety standards to assess the status of unique facility conditions. This software application provides the means to record fire safety assessment results and to generate reports with key evaluation outcomes.

Once site visits have been planned and executed, in accordance with the scope of work statement, any system engineering changes, fire hazards and code compliance deviations noted can easily be imported to the appropriate PB FANS database. The application's query and data storage functionality allow the user to store, retrieve and manage the voluminous data sets that need to be manipulated when carrying out nuclear facility fire safety analyses. Search, filter, sort and data verification functions embedded in PB FANS enable significant efficiencies in updating existing plant data sets and in capturing new data.

When executing FSSA, or FHA, detailed definitions of the fire model scenarios to be conducted, the fire modelling outcomes and the steps taken to resolve and mitigate the impacts of safe shutdown capability all need to be meticulously recorded and the assessment results including deviations and corrective actions logged. All fire modeling is performed externally to PB FANS, using defined model criteria and parameters FANS. The results of the fire modeling are then used to identify impacted nuclear safety equipment and cables and assess the overall impacts of the modeled fire on nuclear safety methods. The SIM automatically determines the success and failure paths resulting from the impacts, greatly facilitating the FSSA computations, especially when building an assessment from a pre-existing plant dataset.

5.4 PB FANS Security

The Integrated Security System manages all users and user permissions for all the Web-based applications running under the Professional Loss Control Inc. (PLC) application framework. All authorized users are managed in a common pool, such that each user has one user name and password that gives access to the applications for which they are authorized.

The PB FANS standard user roles, which govern the permissions and activities within the application are assigned by the Administrator to the registered user. Not all functionality will be available to all users but a user may be assigned more than one role in order to authorize different activities within the application. A user must be assigned at least one role within the application to be allowed access. These roles include the following titles:

- The 'Viewer' Role allows its assigned users to view data within the application, but does not allow them to create, edit or delete any data. This role has the fewest privileges within the security framework.

- The 'Creator' Role allows assigned users to create or enter data records, within the application.

- The 'Editor' Role allows assigned users to edit existing data records.

- The 'Deleter' Role allows assigned users to delete data records within the application.

- The 'Reviewer' Role is a special case role which enables the assigned users to review data within the application. It provides the opportunity for the user to mark their visit by date and time, and indicate that a specific data item has been reviewed. The user with this role assignment cannot edit or delete data. This role operates in conjunction with the other role assignments and its sole purpose is to display and register review functions.

- Custom Roles are other roles which may be created for an application. They confer privileges to a user that are specific to the application.

Using a recommended web-browser, the user must go to the URL for the PB FANS Application, which will be issued when the user's name is registered and password assigned. When the application is first opened, the user is presented with the system log-on page. To access the application, the user must enter their assigned user name and password. Click 'Log On' and the application access will either be granted or an error message will be displayed, informing the user as to the reason for the denied access.

6. Conclusion

Since 2002, the PB FANS application has been designed, tested and evolved to continuously improve its functionality – from its original format as a fire safety analyst's toolset to a full fledged nuclear facility application with utilities that support the site configuration data gathering, fire modeling evaluations, deviation tracking, and fire improvement planning process resulting from FSSA, FHA and CCR analyses. The application software will continue to evolve with features that address a facility's space allocation and the ability to conduct transient material analysis.

7. References

[1] PB FANS 2.4 User Guide Rev. A

[2] PB FANS 2.3 Theory Manual Rev. 0

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[5] US Nuclear Regulatory Commission; NEI 00-01, "*Guidance for Post-Fire Safe Shutdown Analysis"*; Rev 2, 2004.