APPLICATION OF GENERIC EVENT TREES DERIVED FROM THE OECD FIRE DATABASE FOR PROBABILISTIC INVESTIGATIONS OF NUCLEAR POWER PLANTS

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Fire PSA for nuclear power plants (NPP) are performed in order to assess the contribution of fire events to the overall risk of the facility and to identify possible weaknesses within the fire protection concept. The fire event sequence can be generally characterized as a continuous stochastic process depending on manifold random influences. The so-called event tree analysis method is applied for determining the conditional probability of fire induced failures. An event tree is a simplified and discretized form of the stochastic fire process. Fire behavior and development of an incipient fire at a given fire source are analyzed with respect to fire detection, alarm and suppression considering plant layout, combustibles and structural conditions inside the NPP buildings. Fire occurrence frequency as well as branch point probabilities of the event trees have to be determined for quantifying the fire induced damage probabilities. For this purpose, a suitable database is needed.

Databases are efficient tools to collect and process events such as fires in a traceable manner. In the early 2000s the international database OECD FIRE (Fire Incidents Records Exchange) was developed aiming on recording operating experience from nuclear power plants with respect to fire events in a consistent and quality assured manner. Meanwhile this database covers more than 450 event records from twelve OECD NEA (Nuclear Energy Agency) member countries involved in the FIRE Project.

In this paper, the most recent results from probabilistic analyses and applications of the OECD FIRE Database are presented. In-depth investigations of fire events recorded are e.g. used for deterministic as well as probabilistic assessment of fire protection means within the general concept of nuclear safety. In particular, it is demonstrated that any real fire event can be assigned to a sequence in each of the specified generic event trees. For this purpose, three types of generic event trees have been developed characterizing the fire behavior and development over time (FET-T), the sequence of fire detection and alarm (FET-D) and the time dependent development of fires with respect to the different fire suppression measures including manual fire fighting (FET-S). The results of the corresponding analyses of these three new and complex characteristics (attributes) of fire events are presented and discussed in more detail.

I. INTRODUCTION

The sequence of a fire event can generally be characterized as a continuous stochastic process depending on multiple random influences. In the frame of Fire PSA, the so-called event tree method is applied determining the conditional probability of fire induced failures. An event tree is a simplified and discretized form of the stochastic fire process. Fire behavior and development of an incipient fire at a given fire source are analyzed with respect to fire detection, alarm and suppression, considering plant layout, combustibles and structural conditions inside the NPP buildings. Fire occurrence frequency as well as branch point probabilities of the event trees have to be determined for quantifying the fire induced damage probabilities. For this purpose, a suitable database is needed.

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The main structure of the FIRE Database is outlined in Figure 1.

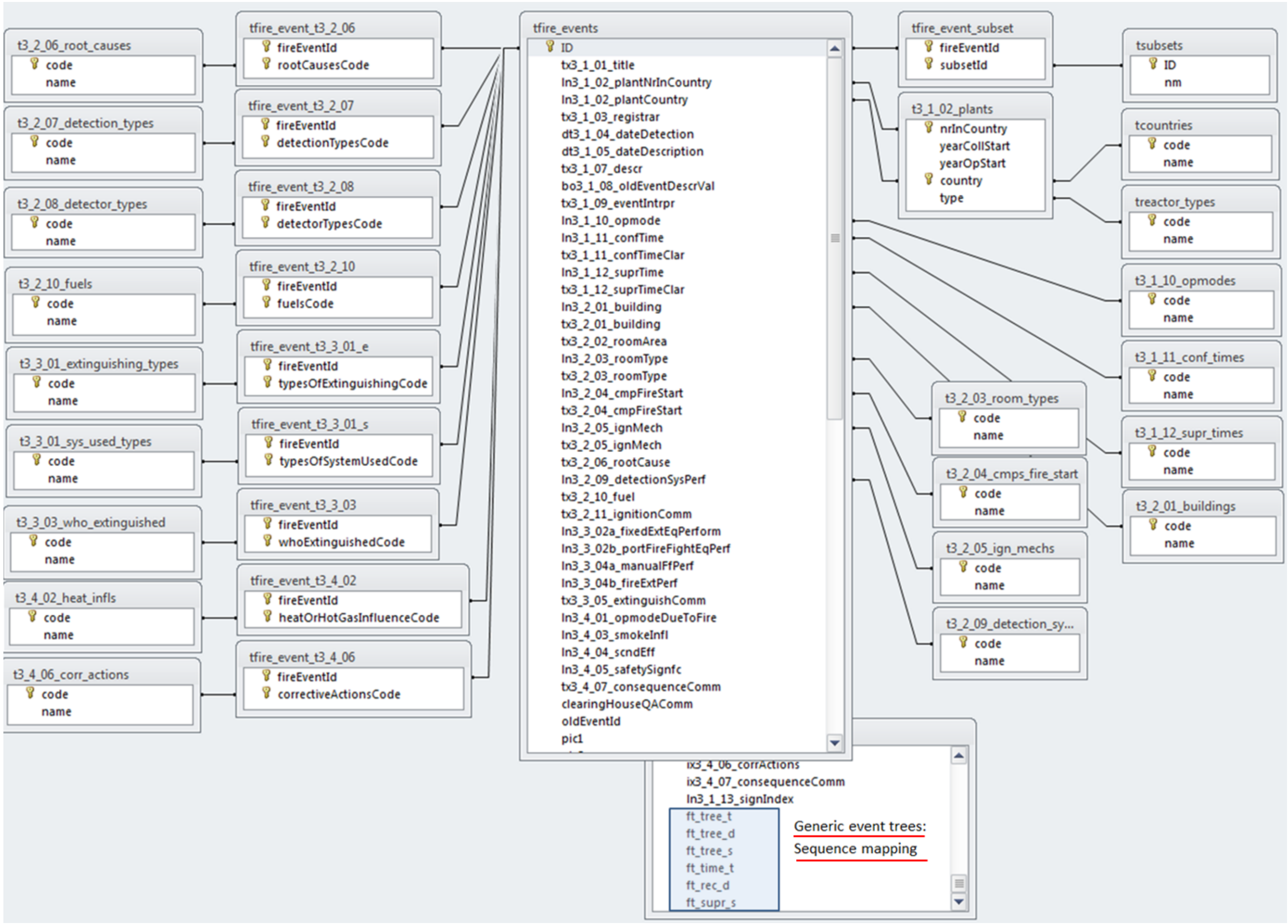

Figure 1. Structure of OECD FIRE Database (extract), from (Ref. 1)

Starting the OECD FIRE Database the analyst gets a menu with various possibilities for browsing, searching, evaluating and analyzing fire events. New features have been implemented for using fire event data from the OECD FIRE Database (Ref. 1), e.g., efficient data handling using subsets and the possibility to characterize the dynamic behavior of fire events by means of new complex attributes. To this end, three generic fire event trees (FET) *FET-T*, *FET-D* and *FET-S* have been developed characterizing the main realizations of fire sequences with respect to time dependent development, detection process and suppression activities. Each fire event stored in the OECD FIRE Database is mapped on the corresponding sequence in each of the three generic event trees. The sequence numbers called *T*, *D* and *S* are complex attributes of a fire event. In the following it is demonstrated how these attributes can be used to assess subsets of fire events.

II. FIRE EVENTS AS TIME DEPENDENT SEQUENCES

The following characteristics of fire events including information on the time dependent event sequence are provided in the OECD FIRE Database (see Figure 2):

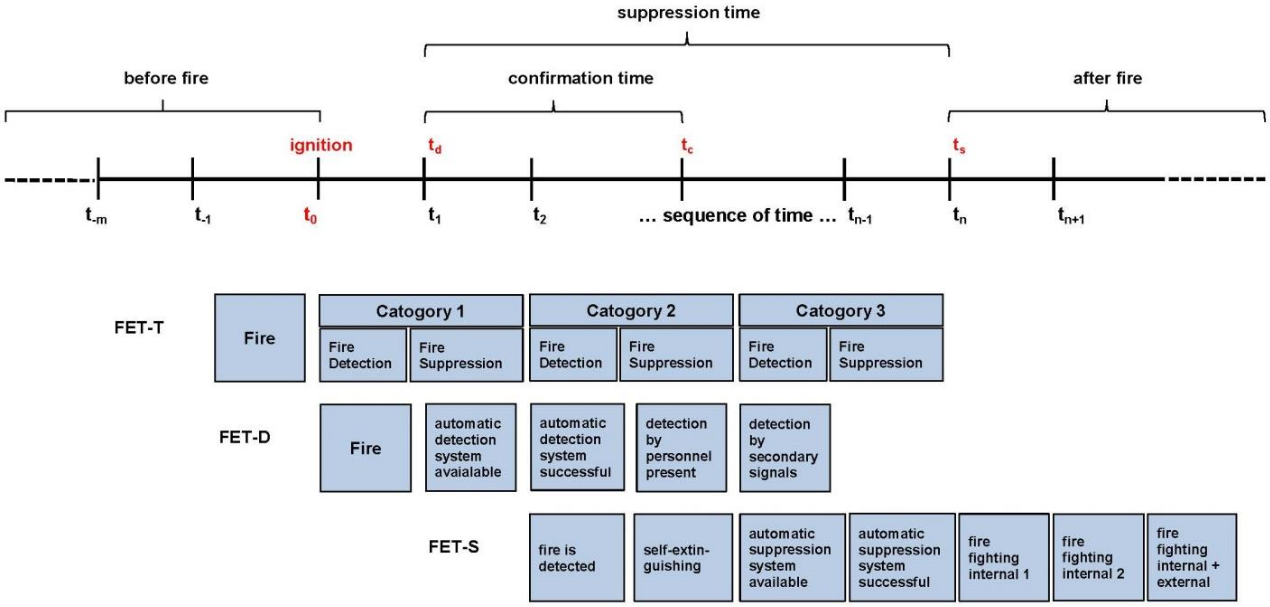

Figure 2. Time dependent event sequence of fire events from fire ignition to suppression

- Sequence of events …, t_{-m}, … t_{-1}, t_0, t_1, t_2, … t_n, t_{n+1}, …
  According to the OECD FIRE Coding Guideline in (Ref. 1) this OECD FIRE Database field contains a *"bullet list with time and description of the event. The reader should be able to understand how the event unfolded in time and logic. Short sentences or statements increase clarity. It should be easy to identify the individual occurrences. Some examples of important occurrences are given: time of the event, time of the alarm, time of the physical localization of the fire, time when extinguishing started, time when fire was under control and time when fire was extinguished."*
  The whole fire event sequence from ignition t_0 to suppression t_s can be coded in the field <tfire_events.ft_tree_t> with explanations in <tfire_events.ft_time_t> (cf. Figure 2). This field contains the mapping of the event to the corresponding sequence of *FET-T* (see Section III). The entire time dependent event sequence depicted in Figure 2 can also be used to characterize the event sequence before and after the incipient fire process from t_0 (fire ignition) to t_s (successful fire suppression).
  As an example for time points between ignition and fire suppression it should be indicated if and when in the event sequence a fire propagates through a fire barrier (e.g., a fire resistant door), if and when the fire spreads to adjacent areas, or if and when other fires start simultaneously in parallel to the initial one.
- Time of ignition t_0
  In the OECD FIRE Database (Ref. 1), no attribute "*ignition time t_0*" does exist. In the majority of events, in particular those from the earlier past, the time of ignition is unknown, in some other cases it is stated that the ignition is immediately detected. Trivially, the detection time as well as the time of suppression are on the right of the ignition time on the time bar (cf. Figure 2).
  There are some supplemental attributes characterizing the ignition phase:
  – building where the fire started,
  – type of room where the fire started,
  – type of component where the fire started,
  – ignition mechanism,
  – root cause,
  – fuel – combustibles – fire loads.
- Fire detection time t_d
  There are additional attributes characterizing the ignition phase:
  – type of fire detection,
  – detector type,
  – detection system performance.

- Confirmation time t_c (and confirmation time clarification)
  The OECD FIRE Coding Guideline in (Ref. 1) defines that this field contains the "*time interval between time of detection and time of confirmation of the fire".* The event specific definition of *"confirmation time"* can be explained in the corresponding text field *"confirmation time clarification".*
  The process of detection and corresponding confirmation can be coded in the field <tfire_events.ft_tree_d> with explanations in <tfire_events.ft_rec_d> (cf. Figure 2). This field contains the mapping of the fire event to the corresponding sequence of *FET-D* (see Section IV).
- Fire suppression time t_s (and suppression time clarification)
  In (Ref. 1) it is defined that the coded field *"suppression time"* contains the *"time interval between time of detection" (<3.1.3 Date and time of detection>)* and *"time of suppression"* of the fire. The event specific definition of *"suppression time"* can be further explained in the corresponding text field *"suppression time clarification"*.
  The process and sequence of fire suppression can be coded in the field <tfire_events.ft_tree_s> with explanations in <tfire_events.ft_supr_s> (cf. Figure 2). This coded field contains the mapping of the fire event to the corresponding sequence of *FET-S* (see Section IV).
  There are some attributes characterizing the extinguishing phase:
  - type of extinguishing,
  - fixed fire extinguishing system performance,
  - portable fire fighting equipment performance,
  - who extinguished successfully the fire,
  - manual fire fighting performance.

As already outlined before, there are two possibilities for characterizing fire events as time dependent sequences of events:

- Sequence of events …, t_{-m}, … t_{-1}, t_0, t_1, t_2, … t_n, t_{n+1}, …
  In most cases, the outline of fire events on a time bar as shown in Figure 2 (see Section III) represents a rough simplification (model) of the fire reality; however, a detailed time dependent sequence of a fire event can be implemented in the OECD FIRE Database (typically by table <t3_1_08_seq_events>). At the time being, the analyst can make use of this possibility for 382 out of 448 fire events. There are ten fire events which are sequentially subdivided into more than twenty steps. On the other hand, there are so far 71 fire events with incomplete or no information on the time dependent development of the event sequence. For some events, information is available explaining why a long time had been elapsed to suppress the fire, e.g. difficulties to identify the fire source or re-ignition of the fire by different reasons.
- Use of generic event trees FET-T, FET-D and FET-S
  Up to now the entire fire events recorded in the OECD FIRE Database have been classified with respect to the generic aspects in the event trees FET-T, FET-D and FET-S. Section III gives a short overview on how to map a new fire event to the sequences of FET-T, FET-D and FET-S.

III. MAPPING FIRE EVENTS TO GENERIC EVENT TREE SEQUENCES

As a supplement to the description of fire events three secondary attributes for characterizing the event sequences have been implemented as presented in (Ref. 2) and (Ref. 3). Three generic fire event trees form the basis for these attributes (see also Figure 2):

- FET-T (Fire Event Tree – Time)
  FET-T represents the generic fire event tree with the time dependent sequence of actions to successfully suppress and mitigate the fire event. This event tree in principle corresponds to the fire event sequence as given in (Ref. 4).
  In this context, it is important to explain that FET-T is not a classical event tree with a continuous time axis. Instead, it summarizes the outcomes of fire detection and fire suppression actions characterized by three different event categories. The starting point in time is identical for these three categories, representing i.e. when the fire starts. The categories are defined as follows:
  - ***Category 1:***
    This category includes fire event sequences with early manual detection and suppression, characterizing event sequences with early (short-term) fire detection and suppression, typically by personnel present at or close to the fire location.

- ***Category 2:***
  This category contains fire event sequences with early automatic detection and suppression, characterizing event sequences with fires detected by the automatic fire detection systems, and being suppressed by stationary fire extinguishing systems automatically actuated by the fire detection systems.
- ***Category 3:***
  This category covers fire event sequences with early or late detection and late manual suppression, characterizing event sequences with
  - fires that were detected early by plant personnel, but could not be successfully suppressed early by plant personnel,
  - fires being successfully detected early by the automatic fire detection systems, but could not be successfully suppressed by the automatically actuated stationary extinguishing systems, and
  - fires that were detected late (after more than 5 min), e.g. via correct interpretation of secondary or indirect signals by plant personnel, and were successfully suppressed late, either by manual fire fighting means (including late manual actuation of extinguishing systems or by self-extinguishing.

  The upper endpoints of the branches indicate successful fire suppression within 30 min, the lower endpoints indicate suppression taking more than 30 min.

- FET-D (Fire Event Tree – Detection)
  The generic fire event tree FET-D covers details of fire detection and alarm.
- FET-S (Fire Event Tree – Suppression)
  The generic fire event tree FET-S covers details of fire suppression.

Each fire event in the OECD FIRE Database (Ref. 1) is assigned to one sequence in each of the three fire event trees. Detailed guidance for the assignment has already been provided in (Ref. 2).

The entire fire event sequences stored in the OECD FIRE Database have been assigned to generic event trees FET-T, FET-D and FET-S. The results of this assignment are stored in a MS EXCEL® file and can be used by the analyst via a command in the Database main menu for further analysis. The user can check and, if necessary, correct the assignments.

III.A. Decision Making Support by Mapping Events to the Generic Event Tree FET-T

In the following the decision making support applying the generic event tree FET-T is demonstrated as an example. Figure 3 shows the generic event tree itself.

Figure 4 provides the results of the FET-T mapping for all those fire events stored in the OECD FIRE Database where a mapping is possible. In addition, the potential consequences are listed in Table 1. Explanations of the individual time dependent sequences as provided in Table 2, and the definitions of the different branches of the generic event tree are given in Table 3. Each sequence is labeled with an abbreviation, the sequence is outlined in detail, the consequences and at least one example are given hereafter.

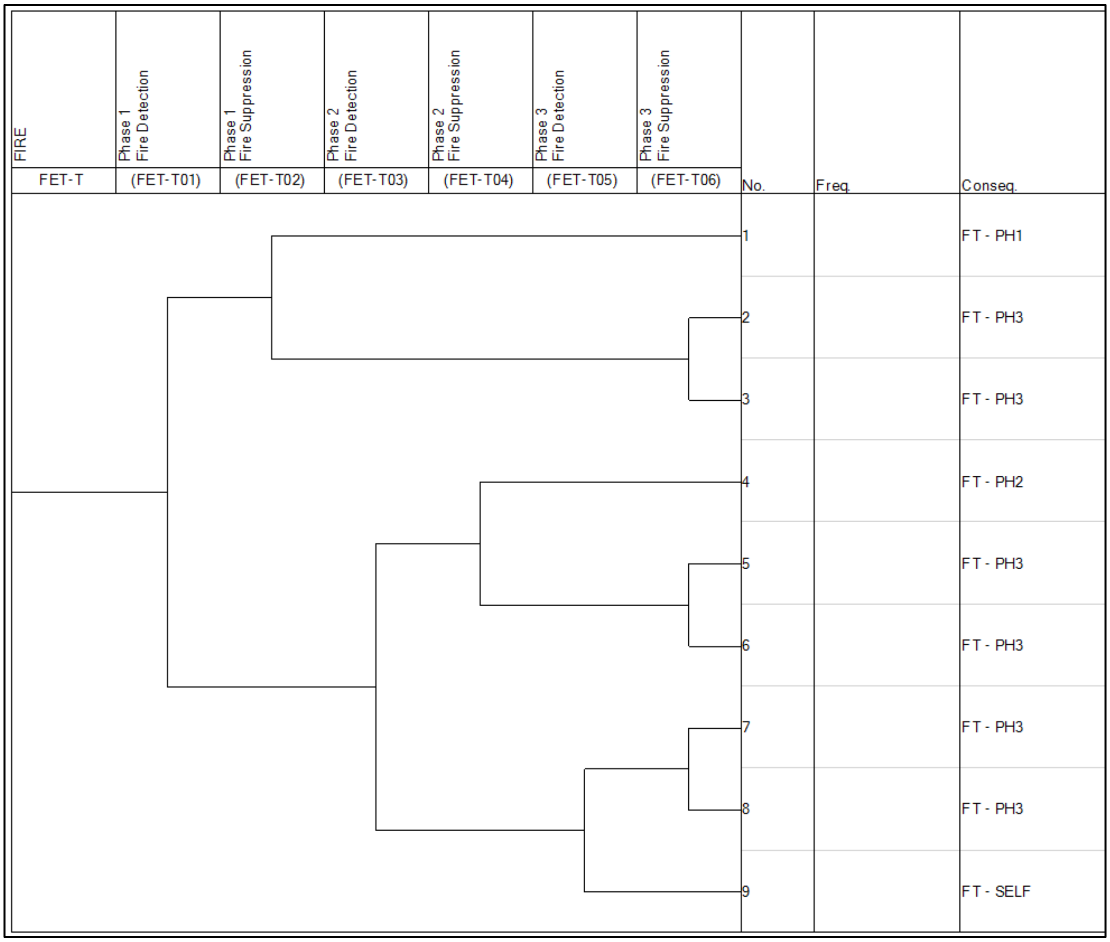

Figure 3. Generic Fire Event Tree – Time (FET-T)

Table 1. Consequences of FET-T

Consequence	Description
FT – Cat 1	Category 1: The fire is extinguished in phase 1.
FT – Cat 2	Category 2: The fire is extinguished in phase 2.
FT – Cat 3	Category 3: The fire is extinguished in phase 3.
FT – SELF	The fire goes out by itself.

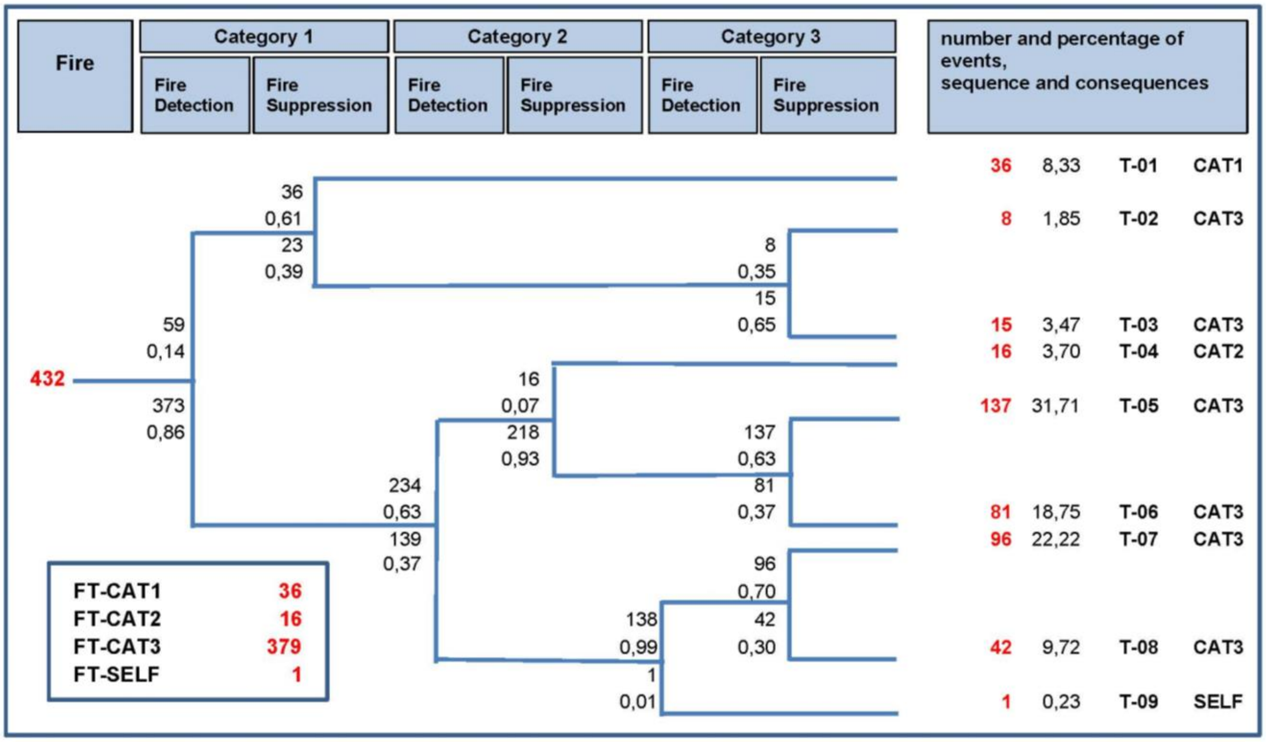

Figure 4. Results of the FET-T mapping for all events in the Database with sufficient information for mapping (representative for 8235 reactor years)

Table 2. Sequences of FET-T

Mapping Parameter / FET-T Sequence No.	Generic Event Characteristics
1 / T01	The fire was detected immediately (by personnel) and successfully suppressed (either by personnel, or it went out by itself).
2 / T02	The fire was detected immediately (by personnel), but not suppressed at once. The fire was successfully extinguished after a short time period (first attempt).
3 / T03	The fire was detected immediately, but not suppressed at once, but after a longer time period. The fire was successfully extinguished by personnel (more than one attempt), or the fire went out by itself, or prompt fire fighting was not possible, but means were initiated resulting in later fire suppression.
4 / T04	The fire was automatically detected and successfully suppressed by automatic fire extinguishing systems in an early stage.
5 / T05	The fire was automatically detected early. Automatic suppression by stationary fire extinguishing systems failed or there was no such system in place. The fire was successfully suppressed either by manual means or went out by itself within 30 min.
6 / T06	The fire was automatically detected. Early suppression by stationary fire extinguishing systems failed. The fire was successfully suppressed after a longer time period (more than 30 min) either by the automatic stationary extinguishing systems, or by personnel, or it went out by itself.

Mapping Parameter / FET-T Sequence No.	Generic Event Characteristics
7 / T07	The fire was detected late (by detection and correct interpretation of secondary signals). Manual fire suppression was then successful within 30 min.
8 / T08	The fire was detected late (by detection and correct interpretation of secondary signals). Fire suppression was successful within more than30 min, either by personnel or the fire went out by itself.
9 / T09	Fire occurrence was detected only after the fire had already self-extinguished.

Table 3. Branches of FET-T

Branches	Description		
FET-T01	Immediate fire detection by personnel present in the fire compartment or near to it. *Remark:* *In this context, immediate means less than 5 min.*	▲	Early fire detection by humans
		▼	No early fire detection by humans
FET-T02	Early fire detection by on-site personnel; fire-fighting by these personnel with resources locally available. (fire suppression directly after detection)	▲	Early fire suppression either by manual means (or self-extinguishing)
		▼	No early fire suppression by manual means (or self-extinguishing)
FET-T03	Early fire detection and alarm by automatic fire detection systems; no early fire suppression (no detection, no extinguishing means)	▲	Early fire detection by automatic means
		▼	No early fire detection by automatic means
FET-T04	Early fire suppression by automatically actuated stationary extinguishing systems	▲	Early fire suppression by automatically actuated means (or self-extinguishing)
		▼	No early fire suppression by automatically actuated means (or self-extinguishing)
FET-T05	No early fire detection and suppression; late fire detection, e.g. by secondary or indirect signals or plant personnel	▲	Late fire detection by personnel or by indirect signals
		▼	Late fire detection by personnel or by indirect signals (however self-extinguishing)
(FET-T06)	Late fire suppression, by plant personnel, on-site or external fire brigade	▲	Late fire suppression by manual means (or self-extinguishing) within 30 min
		▼	No late fire suppression by manual means (or self-extinguishing) within 30 min

The following insights from the FET-T mapping have been gained so far:

The most conspicuous result is the strong dominance of Category 3 events, with 379 of in total 432 events (88 %) for which such as mapping was possible. By definition, fires belonging to this category were extinguished by human actions of various kinds and by various compositions of the fire fighting teams.

Furthermore, Category 1 also contains fire events being extinguished by manual means. These two categories together represent 415 of the overall 432 events (96 %) of the events mapped according to FET-T. In case of 277 (66 %) of these events the fire was suppressed within less than 30 minutes.

The low number of only 16 Category 2 fire events, which were automatically detected and extinguished, is statistically not very significant. However, as the majority of these fires occurred at large transformers, the absence of automatic detection and of extinguishing systems at transformers might cause wide spread damage.

III.B. Decision Making Support by Mapping Events to the Generic Event Tree FET-D

For the generic event trees FET-D and FET-S guidance similar to that for FET-T (see Subsection III.A) is given. Figure 5 provides the results of the FET-D mapping for all those fire events stored in the OECD FIRE Database where a mapping is possible. Interpretations of the individual time dependent sequences as provided in Table 4.

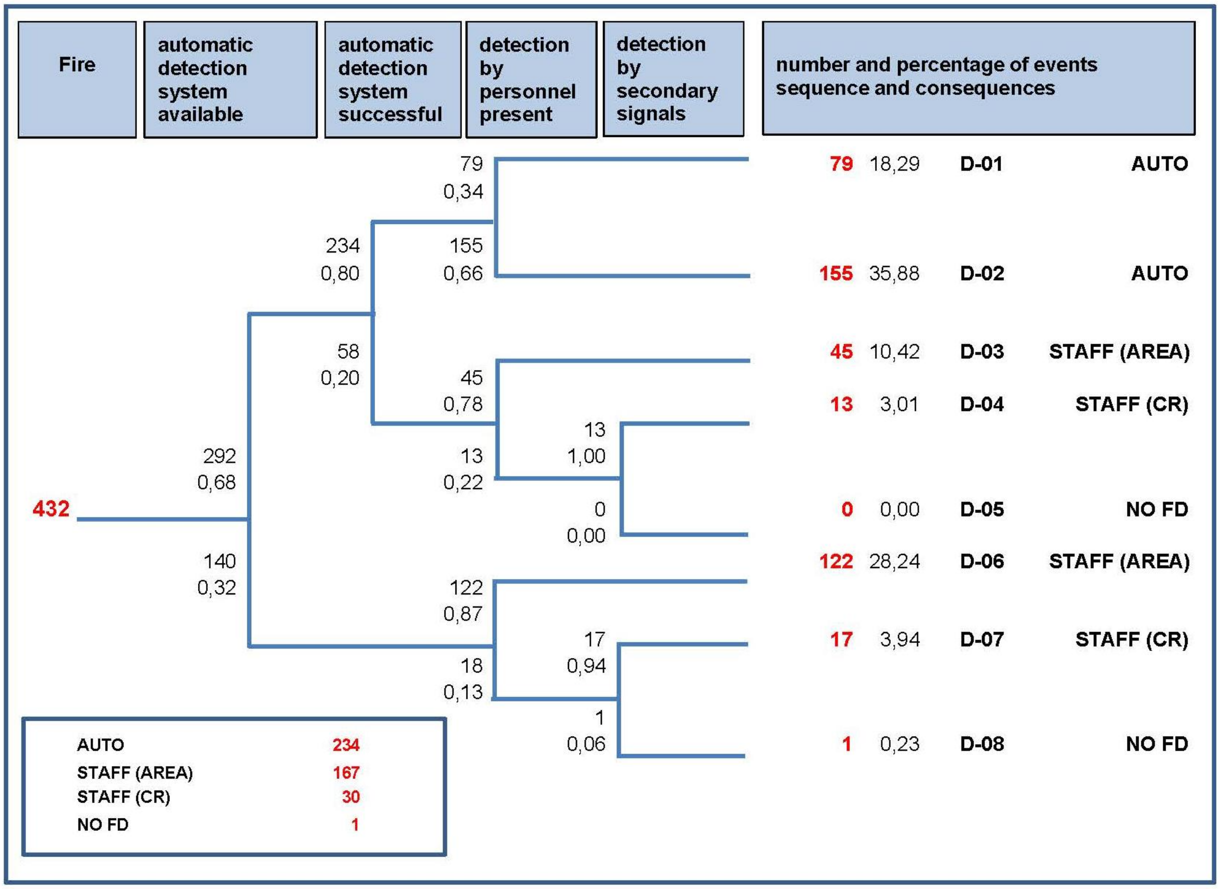

Figure 5. Results of FET-D mapping

Table 4. Sequences of FET-D

Mapping Parameter / FET-D Sequence No.	Generic Event Characteristics
1 / D01	Automatic fire detection systems were in place at the fire location or nearby. The fire detection systems operated as required. The fire was also recognized by personnel or detected by secondary or indirect signals.
2 / D02	Automatic fire detection systems were in place at the fire location or nearby. The fire detection systems operated as required.

Mapping Parameter / FET-D Sequence No.	Generic Event Characteristics
3 / D03	Automatic fire detection systems were in place at the fire location or nearby. Fire detection by the automatic fire detection systems was not successful. The fire was detected and reported by personnel at the fire location or nearby.
4 / D04	Automatic fire detection systems were in place at the fire location or nearby. Fire detection by the automatic fire detection systems was not successful. The fire was not detected and reported by personnel. The fire was detected by secondary or indirect signals.
5 / D05	Automatic fire detection systems were in place at the fire location or nearby. Fire detection by the automatic fire detection systems was not successful. The fire was not detected and reported by personnel. The fire was not detected by secondary or indirect signals.
6 / D06	Automatic fire detection systems were not in place at the fire location or nearby. The fire was detected and reported by personnel present at the fire location or nearby.
7 / D07	Automatic fire detection systems were not in place at the fire location or nearby. The fire was not detected and reported by personnel. The fire was detected by secondary or indirect signals.
8 / D08	Automatic fire detection systems were not in place at the fire location or nearby. The fire was not detected and reported by personnel. There were no secondary or indirect signals or these signals were not recognized.

The following insights from the FET-D mapping have been gained so far regarding fire detection:

One important observation is that 292 out of the 432 mapped events (representing approx. 67 %) occurred at locations where automatic fire detectors were installed. In case of 234 fires the automatic fire detection was successful while in case of 58 fire events the fires were detected by plant staff being mostly at or near the fire location.

Otherwise (58 cases), the fires were detected by plant personnel present in the fire compartment or in a plant area very close to the fire location.

At fire locations without automatic fire detectors being present (this was the case for 140 of the 432 events mapped) the fire was detected by humans being present at that location or close to it. Only one fire was not detected, the observation that there had been a fire was made after the fire already was out (self-extinguished, generic sequence T-09).

III.C. Decision Making Support by Mapping Events to the Generic Event Tree FET-S

For the generic event tree on fire suppression FET-S Figure 6 shows the results of the mapping for all those fire events stored in the OECD FIRE Database where such mapping is possible. Interpretations of the individual time dependent sequences as provided in Table 5.

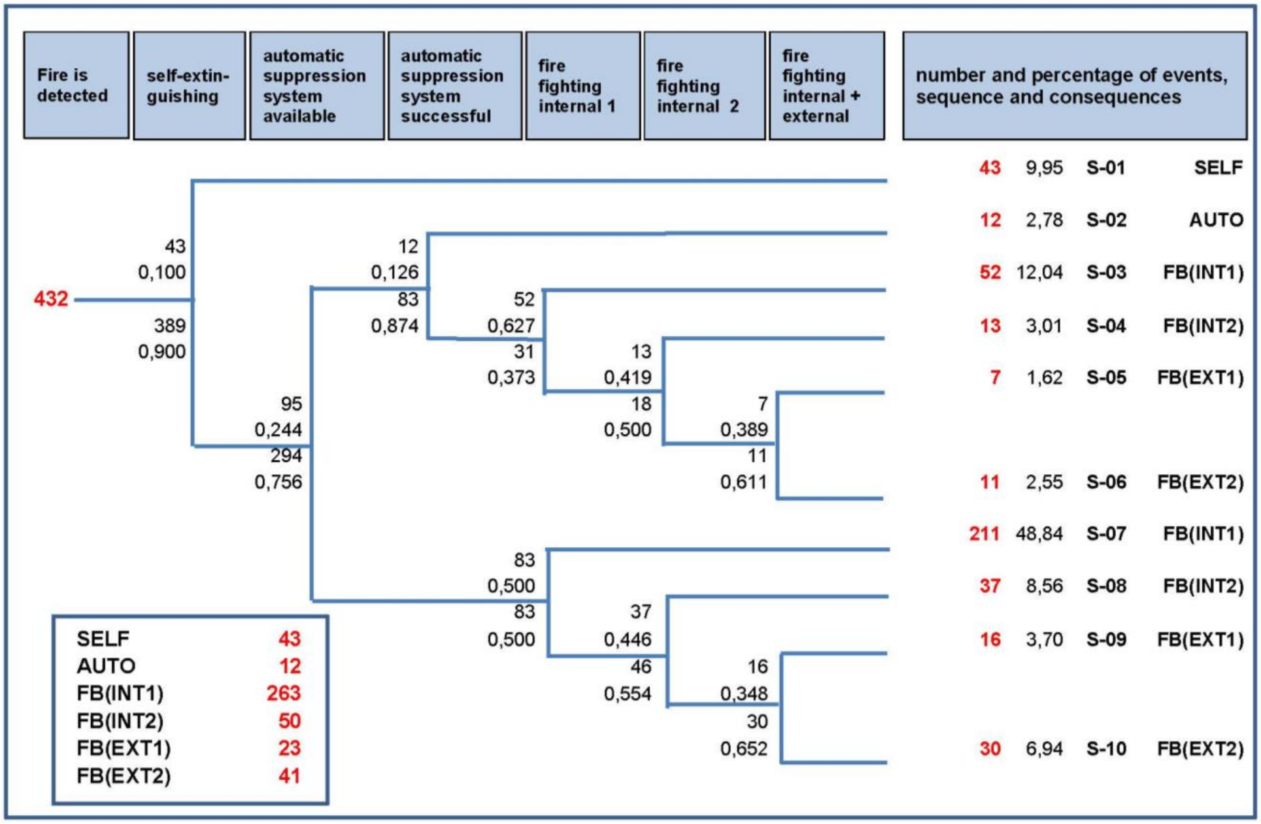

Figure 6. Results of FET-S mapping

Table 5. Sequences of FET-S

Mapping Parameter / FET-S Sequence No.	Generic Event Characteristics
1 / S01	The fire self-extinguished (i.e., the fire went out by itself by lack of fuel or oxygen). There were no attempts to fight the fire.
2 /S02	A stationary fire extinguishing system was in place at the fire location. The stationary fire extinguishing system operated as required. The fire was successfully suppressed by the automatic fire extinguishing system.
3 / S03	A stationary fire extinguishing system was in place at the fire location. Fire suppression by the stationary fire extinguishing systems was not successful. The fire was successfully suppressed by plant personnel present or internal fire brigade (first attempt).
4 / S04	A stationary extinguishing system was in place at the fire location. Fire suppression by the stationary fire extinguishing systems was not successful. Fire suppression by plant personnel present or internal fire brigade in the first attempt was not successful. Fire suppression by more than one attempt was successful.
5 / S05	A stationary fire extinguishing system was in place at the fire location. Fire suppression by the stationary fire extinguishing systems was not successful. Fire suppression by plant personnel present or internal fire brigade was not successful. Fire suppression was finally successful by support of an external fire brigade (first attempt).

Mapping Parameter / FET-S Sequence No.	Generic Event Characteristics
6 / S06	A stationary fire extinguishing system was in place at the fire location. Fire suppression by the stationary fire extinguishing systems was not successful. Fire suppression by plant personnel present or internal fire brigade was not successful. Fire suppression was finally successful by support of an external fire brigade (more than one attempt) or fire self-extinguished from lack of fuel or oxygen.
7 / S07	A stationary fire extinguishing system was not in place at the fire location. Fire suppression by plant personnel present or internal fire brigade was successful (first attempt) or by controlled burn-out.
8 / S08	A stationary fire extinguishing system was not in place at the fire location. Fire suppression by plant personnel present or internal fire brigade was not successful (first attempt). Fire suppression by more than one attempt was successful.
9 / S09	A stationary fire extinguishing system was not in place at the fire location. Fire suppression by plant personnel present or internal fire brigade was not successful. Fire suppression was finally successful by support of an external fire brigade (first attempt).
10 / S10	A stationary fire extinguishing system was not in place at the fire location. Fire suppression by plant personnel present or internal fire brigade was not successful. Fire suppression was not successful by support of an external fire brigade (first attempt Fire suppression by more than one attempt was successful or fire self-extinguished by lack of fuel or oxygen.

The following observations from the FET-S mapping have been made so far regarding fire suppression:

A total of 263 out of 432 mapped fire events (representing approx. 61 %) were successfully extinguished with only one attempt by plant personnel, while 50 fires (approx. 12 %) required more than one attempt by plant personnel. In case of 64 fires (approx. 15 %) external fire fighters participated in the activities to successfully extinguish the fire, in case of 41 events (approx. 9 %) more than one attempt was needed. These numbers demonstrate how reliable and efficient an on-site professional fire brigade is for fire mitigation. This mainly results from high skills, regular training, and plant familiarization.

In case of 43 out of the mapped 432 events (representing approx. 10 %) the fire self-extinguished due to lack of fuel or oxygen. Again, only one fire was not detected and self-extinguished, the observation that there had been a fire was made after the fire already was out (generic sequence T-09).

The results of the mapping to the generic event trees FET-T, FET-D and FET-S are remarkably robust. This could be demonstrated by comparing e.g. the FET-T trees for all events with those for the subsets of PWR (*p*ressurized *w*ater *r*eactor) units (cf. Figure 7), and BWR (*b*oiling *w*ater *r*eactor) plant units respectively shown below in Figure 8.

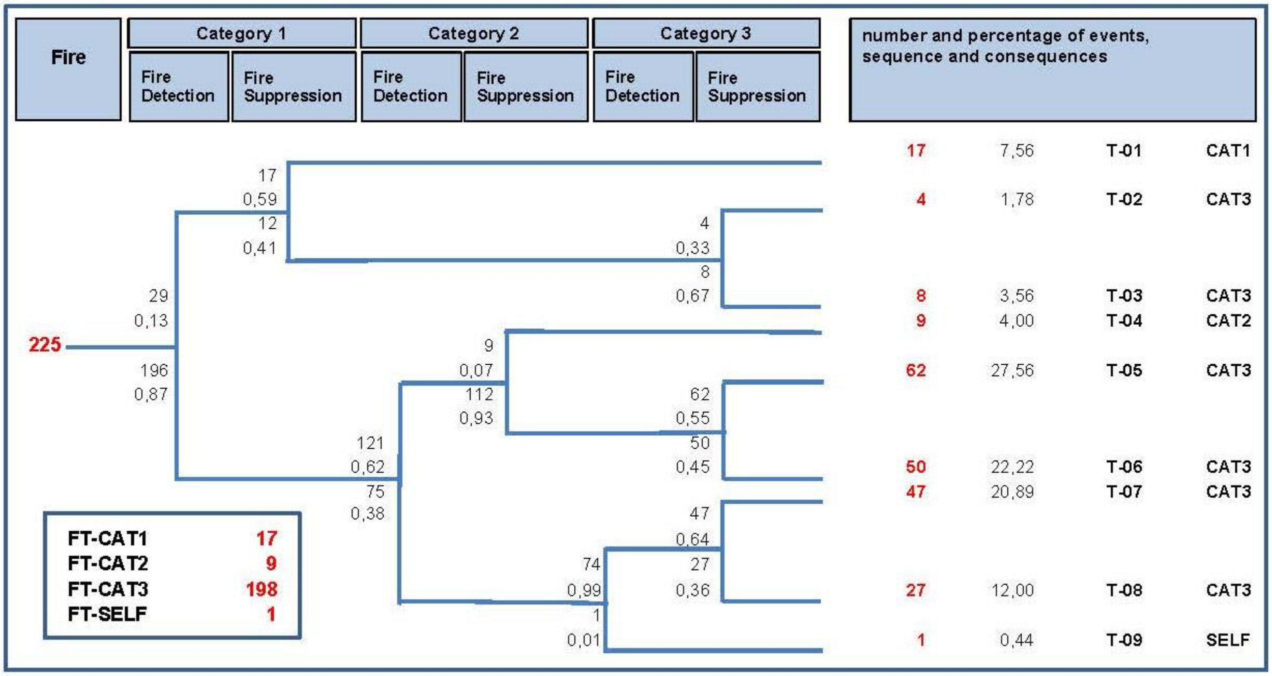

Figure 7. Results of the FET-T mapping for all PWR evens in the database with sufficient information for mapping (representing 5002 reactor years)

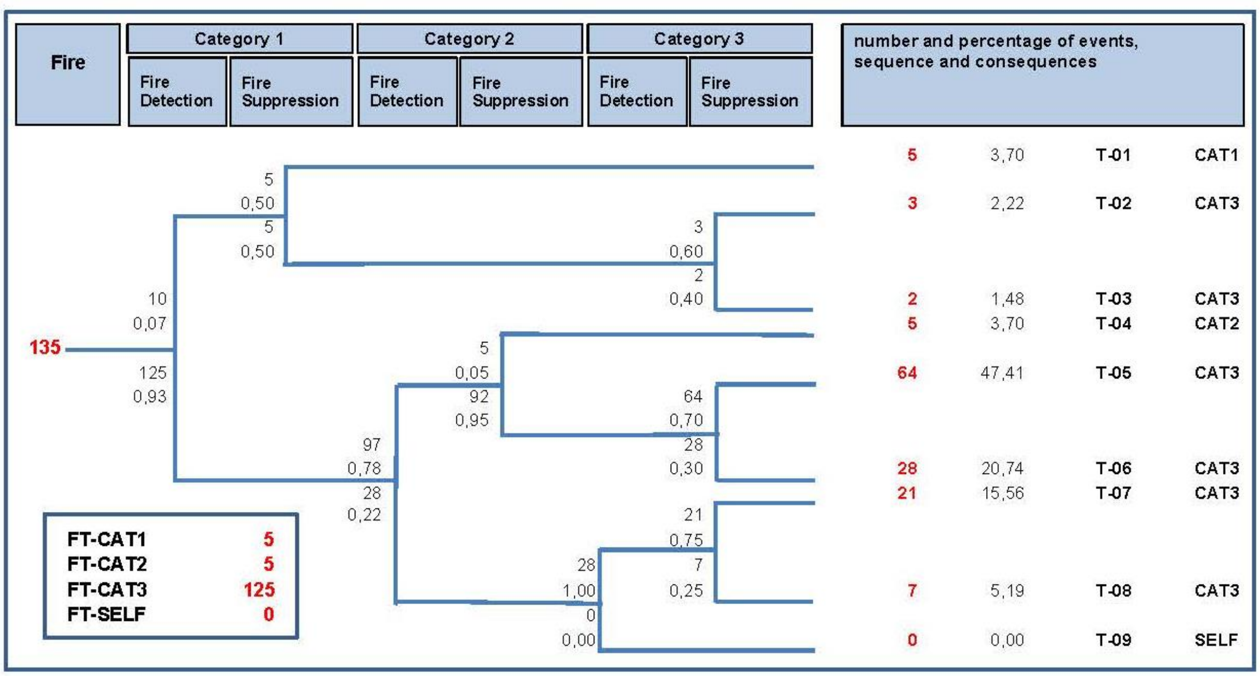

Figure 8. Results of the FET-T mapping for all BWR events in the database with sufficient information for mapping (representing 2565 reactor years)

The branch point probabilities for these subsets agree reasonably well between themselves and are well in line with the numbers for the event tree FET-T, all events. The same is true for the FET-D and FET-S trees (not shown for reasons of space for PWR and BWR.

IV. USE OF DATABASE SUBSETS

The best possibility for browsing fire events in the OECD FIRE Database is using the button '*View Fire Events*' in the main menu of the OECD FIRE Database (Ref. 2). For each fire event most of the information recorded is shown in the categories "*general data*", "*ignition phase*", "*extinguishing phase*" and "*functional consequences and corrective actions*" in Figure 9 below.

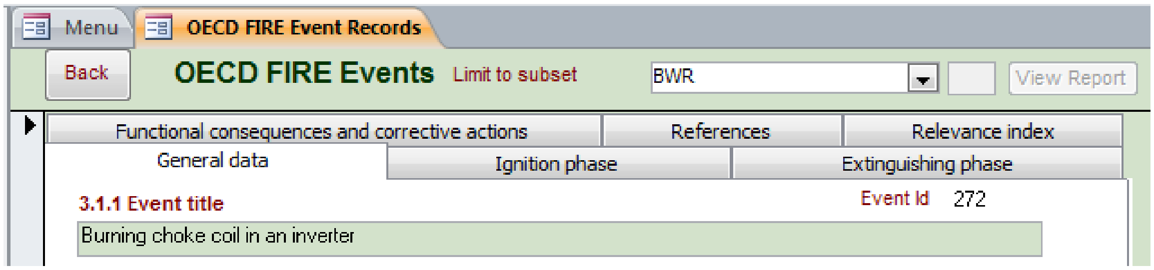

Figure 9. Heading of fire event form in the OECD FIRE Database, from (Ref. 1)

The actions of browsing, searching and evaluation can be restricted to subsets. In Figure 9 the exemplary browsing is restricted to fire events from boiling water reactors (BWR), see the coded field "*Limit to subset*". In the context of the OECD FIRE Database, subsets are compilations of fire events with similar attributes or similar combinations of attributes. Subsets must be defined depending on the problem to be resolved. For a determination of a subset the buttons "*Search Fire Events*", "*Define Subsets*" or "*Derive Subsets*" can be used.

Subsets can be defined using the search form fixing all the attributes of fire events which characterize the fire events needed for the analysis, e.g. all fire events occurring during power operation from NPP with BWR. To this end, the button *"Search Fire Events"* is used. Subsets can also be defined by checking the fire event IDs in the form which is shown using the button "*Define Subsets*".

Subsets can be handled with mathematical operations such as union, intersection, difference and complement, to this end the button "*Derive Subsets*" is used.

There are interesting attributes of fire events which are not explicitly given in the OECD FIRE Database. Fire events with such attributes can be compiled in subsets, e.g.:

- subset of external fires,
- subset of fires on multi-unit sites,
- subsets of event combinations of fires and other events (from (Ref. 5)),
- subset of self-extinguished fires,
- subset of fires with re-ignition,
- subsets of fires with given consequences of *FET-T*, *FET-D*, *FET-S* or consequence combinations. FET-T, FET-D, FET-S are called '*generic fire event trees*'. The use of such trees to assess fire events is explained in (Ref. 2),
- subsets of fire events with insufficient information.

V. USE OF THE EVALUATION FUNCTION

Valuable insights can be gained from the "*Evaluation*" function, as demonstrated in Figure 10 showing the teams participating in fire extinguishing and giving an overview of the number of times the teams participated. The elements below the diagonal of the table are defined by the *"exact and"* operator (exact doubles, black font); above the diagonal they are defined by the normal *"and"* operator (doubles plus possibly others). If there is a difference between a below-diagonal-element and the corresponding above-diagonal-element, the above-diagonal-element appears in red font. In the example provided here 86 out of 448 fire events (representing approx. 19 %) the fire was suppressed by manual fire-fighting activities of the on-site plant fire brigade alone. In case of 17 events (approx. 4 %) there have been exact doubles of the manually actuated stationary extinguishing systems and the on-site fire brigade. The other doubles have been 4 with automatically actuated stationary fire extinguishing system, 1 with fire guard/watch, 18 with participation of the external fire brigade (numbers to the left of "88"), 18 with people present in the fire area, 16 self-extinguished and 9 with shift personnel (numbers below "88").

	External fire brigade	Fire guard/watch	Fixed system - Automatic actuation	Fixed system - Manual actuation	On-site plant fire brigade	People available in the fire area	Self-extinguished	Shift personnel
External fire brigade	3		12	21	39	4	5	17
Fire guard/watch		4	2	3	3	3		2
Fixed system - Automatic actuation	1		12	14	21	1		7
Fixed system - Manual actuation	5			1	42	7		21
On-site plant fire brigade	18	1	4	17	86	23	18	21
People available in the fire area	2	1	1	2	18	46	11	10
Self-extinguished					16	9	44	25
Shift personnel	5		2	6	9	3	17	29

Figure 10. Who extinguished successfully the fire and how often

	Fire guard/watch	Fixed system - Automatic actuation	Fixed system - Manual actuation	People available in the fire area	Self-extinguished	Shift personnel	Unknown
Fire guard/watch							
Fixed system - Automatic actuation		6	3				
Fixed system - Manual actuation		3	7	1		1	
People available in the fire area			1	1			
Self-extinguished						1	
Shift personnel			1		1	1	
Unknown							

Figure 11. More than double combinations of on-site plant fire brigade and external fire brigade

The “39” printed in red for the combination of on-site fire brigade and participating external fire brigade indicates that further 21 events contain the double “On-site plant fire brigade” and “External fire brigade” together with others (normal *“and”* operation). Clicking on the red “39” shows (by the numbers on and above the diagonal of Figure 11) which these are and how often they occur. For example, additional to the 18 doubles of the “On-site plant fire brigade” and “External fire brigade” there are seven triples containing also “Fixed system - Manual actuation”, 3 quadruples containing also “Fixed system - Manual actuation” and “Fixed system - Automatic actuation”, 1 quadruple containing also “Fixed system - Manual actuation” and “People available in the fire area” and 1 quadruple containing also “Fixed system - Manual actuation” and Shift personnel”. In the same manner all other combinations can be analyzed.

VI. CONCLUSIONS AND OUTLOOK

The amount of information in the OECD FIRE Database on fire events in nuclear power plants is continuously increasing. On the basis of currently 448 fire events in the most recent version distributed to members in early 2016 (Ref. 1) a lot of correlations between attributes of fire events are found using descriptive methods. Some of the results have been described before. A comprehensive report will be released in the near future (Ref. 2).

In the future it is important to check the results with methods of mathematical statistics. With such methods it can be verified if the discovered differences, variations or similarities of fire events are statistically significant. Statistical methods and approaches (e.g., tests of independence, correlation tests, cluster analyses, estimation procedures with confidence specifications or application of measures of associations for cross classifications) should be applied if suited. It should be envisaged that these first estimation approaches will be incorporated in a general concept of statistical assessments.

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