FIRE RISK MANAGEMENT SYSTEM FOR SAFE OPERATION OF LARGE ATMOSPHERIC STORAGE TANKS

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FRAMEWORK

Fire risk analysis connected with specific accident scenarios has become an invaluable tool to determine the existing situations safety level, to assure an effective protection level during design (also in order to avoid costly subsequent redesign) and for effectively integrate fire protection criteria and features into project specifications in case of new plants. In the last years different methodologies have been developed by fire engineers for fire risk assessment. A performance-based approach to fire safety is based on established fire safety goals and objectives, deterministic and probabilistic analysis of fire scenarios and quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies and performance criteria. Performance analysis is conducted from a quantitative risk analysis and leads, once risk acceptability criteria has been established, to interventions plans drafting for exiting industrial realities in order to proceed with the adjustment or design of the systems with the determined protection measures. Risk analysis allows to take better informed decisions regarding safety problems of the existing plants and/or plant modifications, to improve the general safety level with a risk reduction supported by effective and cost-effective protection measures, to start adjustment plans for both complex and large plant realities taking into account the risk connected with specific phenomena, the time frames and costs needed to implement the protection measures, etc. in order to reach the prefixed goals. This paper aim is provide the readers for practical examples (case studies) of the research conducted by the authors on the application of a recent and international performance-based methodology (supported by 16 international oil companies) intended to wide the knowledge of the fire risks connected with the operation of large floating roof atmospheric storage tanks (> 40 m diameter) and to determine the risk reduction policies that take into account the specific features of the sites, of the country regulation, of the risk acceptability criteria of the company , of the fire fighting protection standards in use. This paper appears to be quite actual also in consideration of recent fire accidents, among them the Buncefield (UK) terminal fire (11st december 2005).

This methodology sets as an effective “Fire Hazard Management Approach” in line with the most recent trends, even in the regulations, shared at international levels, that propose the integration of risk analysis in the “Safety Cases” preparation activities in which all the aspects connected with the risk mitigation (in favour of the ALARP approach) are taken into account, including the accident prevention itself, differently from the classical prescriptive methodologies focused on protection measures rather than prevention. The proposed approach, is based on potential reference scenarios (modified and characterized by the risk analyst) that relay on an in-depth historical analysis conducted at international level, on the long industrial experience of several oil companies, and manageable through risk reduction measures (technological, procedural, etc. as suggested in the most modern organization management systems).

The proposed methodology is based on several subsequent steps (that can be run across, in a performance based approach, even in a recursive way in order to better characterize and define the problem and to estimate the performance of different improvements), summarized in:

- analysis of fire scenarios (ignition sources, dangerous and flammable goods and chemicals, accident description, consequence estimation, operative experience, QRA in major accidents approach, etc.);
- determination and comparison of risk reduction measures (fire engineering, accidental event evolution, costs and benefits analysis, etc.);
- determination of the risk acceptability criteria taking into account the regulation (also for urban planning purposes) and Fire Hazard Management Policy elaboration;
- fire risk management system improvement plan elaboration (technical, organizational, procedural improvements, emergency planning, HSE training, internal standards review, etc.).

1.0 SCOPE OF THE WORK

The methodology is mainly based on a cost-benefit analysis framework that involves an assessment of a site's existing level of risk and the potential levels of risk reduction that can be achieved by implementing particular risk reduction measures; it provides a tool to help identify the most appropriate and cost effective risk mitigation options which in itself should be one component of a co-ordinated fire hazard management process.

The first step is the means to establish the actual level of risk with an existing facility and then to quantify the potential risk reduction that can be achieved with particular risk mitigation measures.

Fundamental elements in this process are supposed to guarantee an understanding and quantification of existing level of risk and also the ability to quantify and compare the level of risk reduction that can be obtained from any range of potential risk reduction options.

The philosophy of the risk management is not only what can be done but rather what is appropriate to be done, adopting a cost-benefit analysis framework to identify which measure or combination of measures is the most appropriate and cost effective for a particular tank/site.

The first part of the process involves quantifying the existing fire risk level; this information provides a "base-line" against which risk reductions can be measured. In the first instance, the assessment of existing risk is based on statistical averages of incident occurrences. However these can be modified if the particular tank (or homogeneous group of tanks[1]) examined is known to vary significantly from what might be considered an "average" tank, for example because it has a full surface fixed protection system.

Having identified one or more potential risk mitigation options, the methodology provides for a iterative mechanism with which the risk reduction obtainable with different options can be quantified and compared with other solutions.

This methodology is applicable both to existing facilities and new-build facilities where different design philosophies can be compared. In particular the proposed methodology has been developed to deal with risk and safety issues connected with the operation of large atmospheric storage tanks. According to the approach of the methodology it is possible to develop specific similar methodologies to deal with issues related to different systems (i.e. for example process plants) and eventually connected with particular risks characterized by scenarios, evolutions, consequences, risk reduction measures (i.e. for example environmental issues). In general the methodology enforces a performance based approach for Risk.

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[1] Homogeneous tanks are tanks with similar technical particulars such as protection systems and with the same product stocked.

The analysis process is shown in Figure 1.

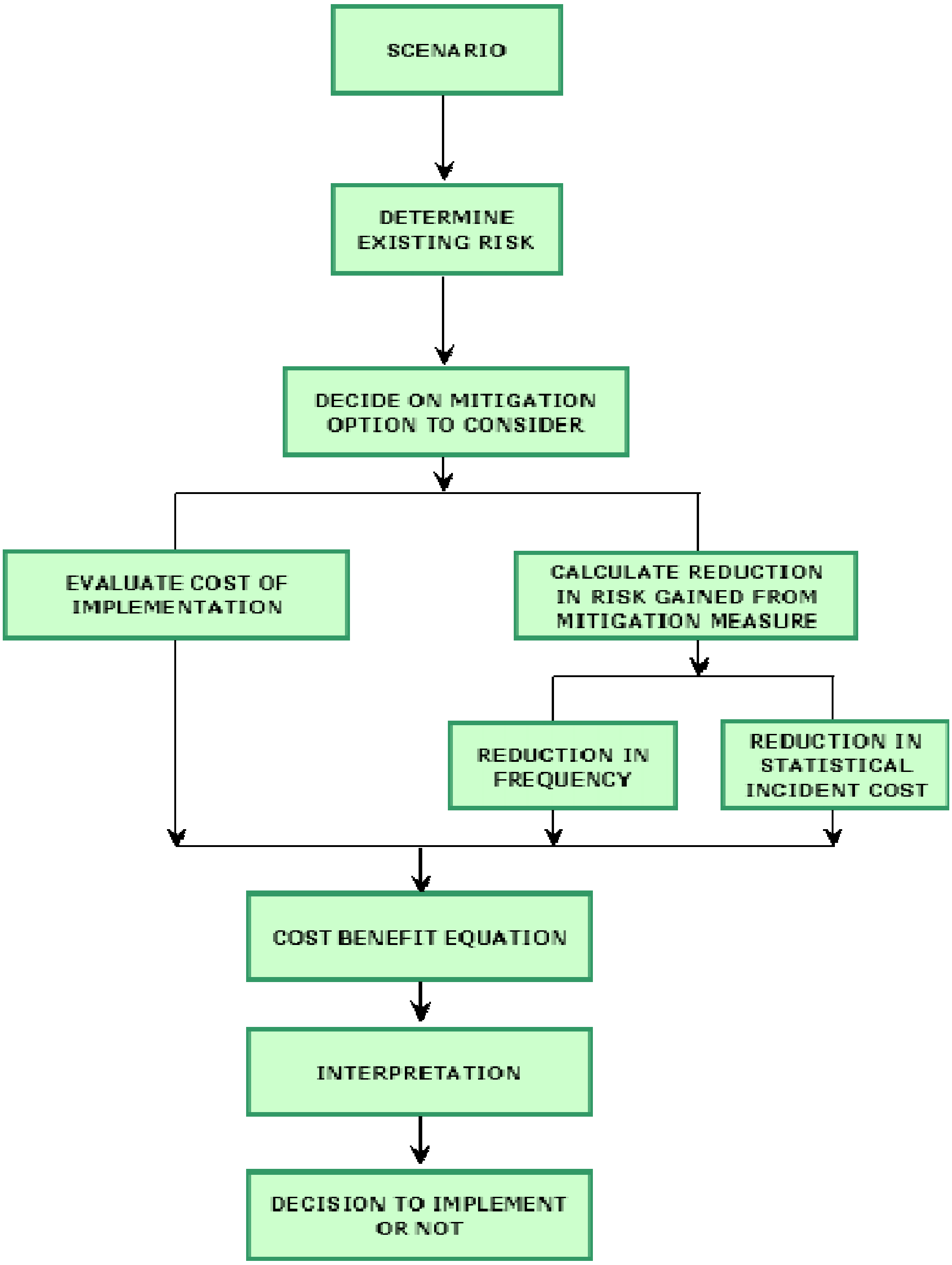

Figure 1. COST BENEFIT ANALYSIS PROCESS

The cost benefit approach adopted involves a comparison of the cost to implement a particular measures against the statistical cost savings that measure can return in terms of reducing the risk of a fire in a large diameter storage tank:

<u>Statistically expected cost of incident without measure</u> – <u>Statistically expected cost of incident with measure</u> > <u>Cost of implementing measure</u>?

It is important to note that risk reduction and a consequential cost saving, can be realized in terms of reducing the *frequency* at which fires occur and/or by reducing the escalation potential and *cost* of an incident should it occur. Cost of an incident is directly connected with other issues (not just the material consequences to human life, environment, etc. and damages to the assets and property) such as the acceptability criteria established by the Company.

In essence the analysis process (iterative) is as follows:

- Identify the scenario(s) that could potentially occur in the tank (or homogeneous group of tanks);
- Make an assessment of the existing level of risk associated with the identified scenario;
- Consider the prevention/mitigation options that could potentially reduce the risk of the chosen scenario;
- Determine the total cost of implementing and maintaining the considered mitigation option;
- Assess the statistical reduction in the levels of risk if the mitigation measure were implemented;
- Determine whether the risk reduction is greater than the cost of implementation.

2.0 IDENTIFICATION OF POTENTIAL SCENARIOS

For the purposes of the cost benefit analysis, it is the initial fire that is considered the "TOP EVENT"; the top events (embedded in the methodology) are:

- Rim seal fire;
- Spill on roof fire;
- Full surface fire;
- Bund fire.

An important part of understanding the fire risk associated with large diameter tanks is an understanding of what are the potential fire scenarios that can occur. The following sub-sections describe the scenarios relevant to open top floating roof storage:

- Rim Seal Fires

A rim seal fire is one where the seal between the tank shell and roof has lost integrity and there is ignited vapour in the seal area. The amount of seal involved in the fire can vary from a small localised area up to the full circumference of the tank. The flammable vapour can occur in various parts of the seal depending on the seal design.

- Spill on Roof

A Spill on roof fire is one where a hydrocarbon spill on the tank roof is ignited but the roof maintains its buoyancy. In addition, flammable vapours escaping through a tank vent or roof fitting may be ignited.

- Full Surface Fires

A full surface fire is one where the tank roof has lost its buoyancy and some or all of the surface of liquid in the tank is exposed and involved in the fire.

- Bund Fires

A fire in a bund is any type of fire that occurs within the containment area outside the tank shell. These types of fire can range from a small spill incident (from tank fittings, flanges and associated pipe-work) up to a fire covering the whole of the bund area. In some cases (such as a fire on a mixer), the resulting fire could incorporate some jet or spray fire characteristic due to the hydrostatic head of the tank's contents.

Ignition Sources

Given that a flammable mixture of hydrocarbon vapour and air exists in any of the above potential scenarios, fire will only result if there is an ignition source present capable of providing sufficient energy (heat) to initiate the combustion process.

With the exception of lightning, ignition sources can generally be related to either some form of manual activity, for example hot work during maintenance, mechanical overheating, remote ignition source (for example a vapour cloud from a release on the tank "finding" a remote ignition source in another part of the installation) or flare stack fall-out. As such, again with the exception of lightening, ignition sources are therefore controlled through appropriate procedures: good practice should always be adopted.

3.0 QUANTIFICATION OF CONSEQUENCES AND EXISTING LEVEL OF RISK

In order to quantify a reduction in the overall risk, the existing level of fire risk must first be estimated This will form the base-line against which the effectiveness of any mitigation measures will be assessed.

The site-specific, indeed tank specific, level of risk will clearly depend on the local operating circumstances and conditions.

Use of statistical average event frequencies combined with an analysis of the escalation potential of the considered incident will be used to determine the statistical cost of the considered incident. Elements such as business interruption, fire-fighting costs, environmental damage and public outrage will all be considered in the cost evaluation.

The statistical cost of an incident (assuming the incident has occurred) is determined from an event tree analysis (ETA) and it is a combination of the potential costs of identified outcomes of the initial event and the conditional probability of each outcome according to the event tree theory.

Determination of existing risk

The risk for a single tank (or for homogeneous group of tanks) is determined from the existing statistical scenario frequency, F [occasion/year] and the statistical cost of the scenario should it occur, C [cost/occasion].

- The scenarios frequencies are estimated means of an international incident survey (to calculate a "statistical average frequency") or by techniques of risk analysis such as HAZOP, FMEA, etc., (to calculate a "local" incidental event frequency): the choice depends by sensitivity and experience of risk analysts. Connection with risk analysis for major accident prevention is fundamental to gather precise data.

- The statistical cost of each of the 4 initiating events considered (TOP EVENTS) are calculated from an event tree analysis. That is, for each initiating event, there is an event tree leading to a number of pre-determined potential outcomes. The likelihood of each of the outcomes actually occurring is determined by the conditional probabilities within the branches of the tree. The overall statistical cost of the initiating event (assuming the event has happened) is then given by the sum of the products of the cost of each of the identified outcomes multiplied by the likelihood of that outcome occurring. The likelihood of each identified outcome is given by the product of the conditional probabilities of all of the branches of the event tree that lead to each outcome:

Statistical cost = ∑ cost of identified outcome X conditional probability of outcome (1)

Conditional probability of outcome = ∏ (conditional probability at each branch of event tree leading to particular outcome) (2)

The event trees for each scenario have been constructed to be flexible enough to allow the full range of mitigation measures to be considered while remaining consistent with the quality of the available data; there is one event tree for each of the four initiating events considered: rim seal fire, spill on roof fire, full surface fire and bund fire.

An example of event tree to estimate the statistical cost of an incidental scenario is reported in Fig.2.

It is recommended that the average conditional probabilities are used as the basis for an analysis. However these should be considered in terms of the specific tank under consideration and the conditional probabilities may be modified according to sensitivity and experience of risk analysts. The costs of each identified outcome in the event tree can be estimated using the pro-forma reported in table 1.

Table 1. PRO-FORMA TO EVALUATE COST ELEMENTS OF A FIRE INCIDENT (Single Outcome)

Fire Fighting Cost	Third party fire fighters		€
	Foam stock replacement		€
	Post-incident clean-up		€
	System re-commisioning		€
Tank(s) Re-commisioning	Rim seal	Hardware	€
		Installation	€
	Roof	Hardware	€
		Installation	€
	Shell	Hardware	€
		Installation	€
Loss of Product (Including product contamination)			€
Business Interruption			€
Public Image	Direct compensation		€
	Loss of reputation		€
Legislative	Fines		€
	Public enquiries etc.		€
	Retrospective operation changes	Hardware	€
		Operational	€
Insurance			€
TOTAL INCIDENT COST			€

4.0 RISK MITIGATION OPTIONS TO CONSIDER

The risk reduction measure, available for design and operation of open-top floating roof of large atmospheric storage tanks, include prevention measures and damage mitigation measures; they can be divided in:

- Storage tank and bund design and operation (such as geodesic domes, double deck roof, secondary seal, high-high level alarm etc.)
- Incident detection systems (such as gas detectors, liquid detectors, heat and flame detection etc.)
- Fire protection systems (such as foam systems, water spray systems, gaseous agent systems, etc.)
- Portable/Mobile Fire-fighting equipment (such as water and foam monitors, hose reels, etc.).

5.0 COST OF IMPLEMENTATION OF A RISK MITIGATION MEASURE

Analysis of the cost of implementing a specific prevention/mitigation measure will not only determine whether implementation is feasible within budgetary constraints but also whether implementation is cost effective.

For generality and consistency costs are considered in euro € and for flexibility they are broken down in terms of:

- Hardware costs;
- Installation costs;
- Annual maintenance costs.

For calculation of costs associated with implementing a risk mitigation measure it can possible use the following table 2.

Table 2. CALCULATION OF COSTS ASSOCIATED WITH IMPLEMENTING A RISK MITIGATION MEASURE

CAPEX:

Hardware costs		€	(a)
Installation	Labour	€	(b)
	Down-time*	€	(c)
	TOTAL CAPEX	€	(d) = (a)+(b)+(c)

OPEX

Annual maintenance costs		€	(e)
Annual down-time costs for maintenance*		€	(f)
	TOTAL ANNUAL OPEX	€	(g) =(e)+(f)
Total lifetime of measure		€	(h)
	TOTAL LIFETIME OPEX	€	(i) = (g) x (h)
	TOTAL LIFETIME COST	€	(j) = (d)+(i)

* Do not include down-time unless it is due solely to the measure in question (i.e. do not include time if maintenance can be carried out during routine down-time)

Cost of Measure

In the context of the cost benefit analysis, the cost of a particular measure is taken as the total cost over the installation lifetime:

Total cost of particular measure = Capex + [Expected lifetime of system (years) x Annual Opex] (3)

It should be noted that costs assume that the measure will be installed at the next planned shut-down of the tank and therefore tank interruption costs are not included. If a measure was to be installed immediately, requiring the tank to be taken out of service, the costs associated with this must be included in the total cost of implementing the measure.

Expected benefit from Mitigation Measure (Risk Reduction)

Having selected a specific risk mitigation measure to consider, the next requirement is to make a quantified estimate of the level of risk reduction that can be achieved by implementing the measure. The risk may be reduced by either reducing the statistical frequency of the event occurring and/or by reducing the statistical cost of the event should it occur.

Reduction in statistical frequency of incident occurring and reduction in statistical cost of incident

Certain measures are designed to reduce the frequency at which a given scenario may occur while other ones are designed to reduce the cost of an incident should it occur. Such measures may reduce the potential for escalation or increase the effectiveness of a fire fighting response. Examples include a fire- retardant rim seal material, installation of fixed fire protection systems and pre-fire plans for cooling of adjacent tanks.

Some measures may reduce both the incident frequency and the incident cost. An example might be a double rim seal made from fire retardant material that will reduce the probability of loss of containment (hence reduce the incident frequency) and increase the chance of preventing the fire escalating around the rim and ultimately to a full surface fire (hence reducing the incident cost).

6.0 COST BENEFIT ANALYSIS

The cost benefit analysis is based on balancing the cost of implementing a specific measure against the expected gains that the measure will yield in terms of reducing the risk of fire.

Formally the cost benefit equation is written as:

$$[(C_{without} \times F_{without}) - (C_{with} \times F_{with})] \times P_r \text{ (available)} > \text{Cost of implementation of a measure}^{2} \qquad (4)$$

Where: **$C_{without}$:** statistical cost of incident without remedial measure in place (assuming the incident has occurred); **$F_{without}$**: expected statistical frequency of the initiating incidental event if remedial measure is not implemented; **C_{with}**: statistical cost of incident with remedial measure in place (assuming incident has occurred); **F_{with}**: expected statistical frequency of the initiating incidental event if remedial measure is implemented; **P_r**: expected probability that the remedial measure will perform its intended function when called upon; **Cost of implementation:** Expected cost involved in implementing the remedial measure.

It is important to note that **$F_{without}$** e **F_{with}** are the frequencies of the initiating incidental event (TOP EVENTS) and not the frequency of any escalated event. Tha potential consequences of escalation are accounted for in the statistical cost of the incident **$C_{without}$** e **C_{with}** .

Availability of Measure

For a mitigation measure to be able to reduce the risk of a fire, the particular measure must actually perform its intended function when called upon. Availability factor is a requirement that the particular measure functions when activated. An availability factor of one implies that the measure will operate and perform its intended actions when called upon.

In this sense it is advisable to estimate the PFD (Probability of Failure on Demand) of the safety systems (Safety Functions). PFD as defined in the international standards IEC 61511 series on “Functional safety – Safety instrumented systems for the process industry sector.

7.0 INTERPRETATION AND IMPLEMENTATION OF RESULTS

The methodology presented in this document is meant to provide a tool to assist site specific decisions to be made on what constitutes cost effective fire risk mitigation options. As with any analysis, the quality of the results will depend on the quality of the input that will depend on the sensitivity and experience of risk analysts.

[2] This cost must be divided for the total lifetime (years) of measure to have a cost/year.

8.0 METHODOLOGY APPLICATION

The methodology application on several different sites of a well known oil company, leader in the oil business, has been supported by an effective knowledge based informative system that allows the risk analyst:

- to insert specific data and features of the facility;
- to characterize the facility tanks with risk indexes based on weighted check lists that take into account the results of the major accidents risk assessment conducted (Seveso 3 European Directive);
- to identify the reference case (given by the company or determined on the basis of the medium condition of the tanks of the considered facility / of the historical analysis available in the knowledge database of the software itself);
- to insert the risk reduction measures from the knowledge data base of the software;
- to elaborate several fire scenarios and their evolution with specific event trees given by the software according to the reference methodology and editable by the risk analyst in order to make the performance based analysis comparable with the criteria followed in major accidents risk assessment performed;
- to evaluate the risk level connected with different solutions of the single tank or the entire tank farms assets, even estimating the modification of the risk level during time with various risk reduction measures subsequent implementation (with particular reference to the continuous improvement enforced and requested by the Safety Management Systems for Major Accidents Prevention provided by the regulation);
- to elaborate an improvement plan with the costs connected with each improvement, for the single tank, for similar tank in the facility, etc.;
- to make an analysis of the costs connected with the improvement in different situations / assets and solutions in relation with the reduction of the risk determined by them;
- to compare the results of the study with similar assessments made in similar facilities of the same company or facilities in different countries and owned by different companies;
- to have simulation results rendered with spreadsheets and graphs (i.e. in order, for example, to identify the site fire risk level trend against a long period of time characterized by the implementation of several prevention and/or consequence mitigation systems and against specific quotas, such as the tolerable risk level established in the Company acceptability criteria);
- to implement an enterprise wide tool supporting the Continuous Risk Management of the Organization (CRM, as defined by the risk analysis teams at Goddard Space Flight Center) characterized by a Risk Life Cycle (RLF, as defined by Johnson Space Center where Risk Management Programs implementation guidelines has been established on the basis of NASA Program and Project Management and Requirements, NASA Policy Guideline 7120.5C);
- to take better informed decisions even on the basis of influence diagrams and decision trees having guaranteed an insight view into real-world safety related problems, showing how you can manage, mitigate and capitalize on the uncertainty in a business or asset for Real Option Valuation (ROV) where An option is the right, but not the obligation, do something (usually buy or sell some asset) at some time in the future after learning about uncertainty. The source of uncertainty is called the underlying. A real option is an option where the underlying is not generally traded. In areas with a high degree of uncertainty, management, knowingly or not, creates and exercises real options on a regular basis. In a decision tree, real options are represented by "downstream" decisions -- that is, decision nodes which follow one or more chance nodes.

Indeed the developed software is flexible enough, thanks to an object oriented model underneath and an ETA/FTA calculation & rendering runtime engine, to be employed as a qualitative/quantitative tool to face specific issues related to risk reduction, perhaps incorporating several other approaches such as LOPA and calibrated risk graphs. An example of methodology application through the tool is reported in the following picture where is possible to see a typical event tree for a particular top event: rim seal fire.

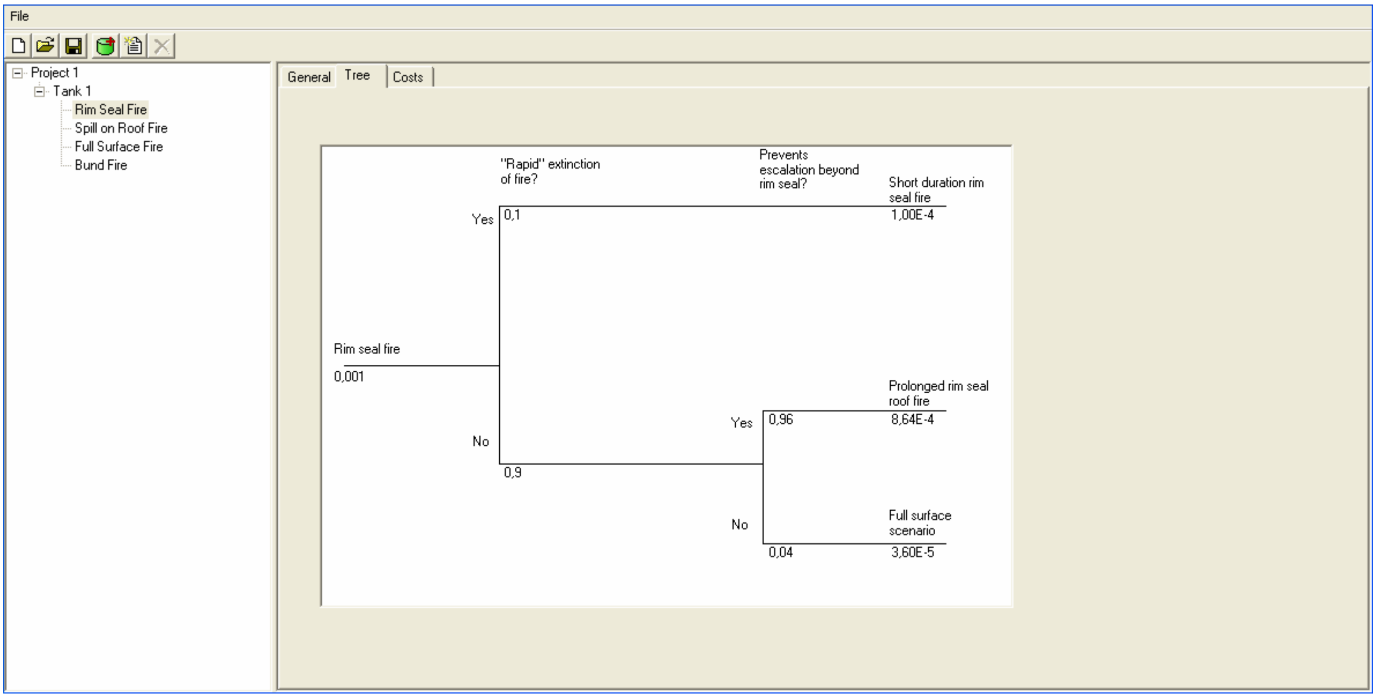

Figure 2. Event tree (runtime generated and fully customizable)
for rim seal fire to estimate the statistical cost of the incidental scenario

9.0 RESULTS

The approach used for the large storage tanks fire risk management is adequate both with the most recent performance based approaches to fire risk and with the ultimate methodologies connected with the environmental risk (both in terms of chemical spreading in soil, and fugitive emissions in atmosphere) coming from same tanks and strictly connected with the typology of the chemicals (i.e. hydrocarbons, fuels, dangerous chemicals from the environment).

Knowledge of the existing software will be improved in order to:

- estimate the environmental risk level using both check lists and index based methodologies (APAT activities, etc.) and estimate the environmental consequences in relation with the peculiarities of the site using integrated and recognized calculation codes (i.e. EPA HSSM, etc.);

- estimate the emission levels with recognized algorithms (i.e. EPA, Environmental Protection Agency 42, Chapter 7, etc.);

- face in an integrate manner both the fire risk and the environmental risk connected with large atmospheric tanks, resulting in integrated improvement plans;

- eventually integrate a GIS based rendering options in order to correlate existing/achievable risk levels with the position of the risk generating objects on territory maps.

- adapt the tool in order to use it for the selection of a remediation strategy for a contaminated waste site: after identification of different tactical pieces that can be bundled into strategies, the tools can be employed to calculate cost, time, and performance attributes for each strategy, using a spreadsheet-like interface. Once final cost, time, and performance values are known for each strategy, utility values are calculated using utility functions and weights derived from the site owners (Organization) and the key decision makers (among them risk analysts). The site owners are able to use the results as part of their Remedial Investigation/Feasibility Study Report to the Authorities.

- adapt the tool to budgeting for pollution prevention projects in order prepare funding strategies for pollution prevention projects. Decision analysis is the basis for a capital budgeting process that takes into account several of the key budgeting issues facing environmental managers, including combining environmental projects with other business projects in the budget evaluation process, and considering the costs, savings and general environmental benefits associated with pollution prevention projects. An important component of the process is the ability to use sensitivity analysis to understand the budget implications of changing project economic and environmental factors. The tool gives in this sense the input and preliminary data for more specialized decision supporting tools.

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