BP Texas Refinery Isomerisation Unit Explosion in 2005; Top Event of What Happened and Consequences:

This is the incidence on BP Texas Refinery explosion that took place on March 23rd, 2005. The whole explosion incidence was initiated at the isomerisation unit. There was inflow of flammable liquids into the raffinate splitter tower. Normally, the tower was designed to store about 6.5 to 10ft volume of liquid and the installed level indicator on this tower was designed to signal the control room on the level of liquid at the tower bottom at every point in time.

On this day of the incidence, a high level alarm triggered and sounded in the control room due to tower overflow but the second (standby/backup) alarm failed. Due to the alarm that sounded, the liquid input was stopped and the level indicator reading was 10ft volume of liquid at the tower bottom. But subsequently, it was found out that the indicator reading was misleading as the actual level of liquid at the bottom of the tower was 13ft which was above the designed level limit of 10ft.

As part of the refinery process, burners were lit to distil the liquid feed in the tower and more liquid was fed into the tower. The operators weren't aware that the valves responsible for outflow of the distilled from the tower to the storage tanks were locked and this caused a high liquid level build up in the tower about 20 times its design limit. The liquid build up led to increased pressure in the tower and the pressure control valve failed. The failure of this valve triggered high pressure alarm. Sequel to this, two burners were put off and the manual chain valve was opened to release gases to the atmosphere through the blow down drum. After this, the operators let the valves to the storage tank open.

As a result of the already liquid build up in the tower, the temperature of the feed through the heat exchangers in the tower was raised by over 150 degrees above the normal temperature and this led to the boiling of the liquid and this caused subsequent overflow of liquids into the pipes at the top of the tower. Due to this overflow, too much pressure was mounted on the emergency release valves which later opened causing liquids to build up at the blow down drum, the high level alarm at the blow down drum failed to sound resulting in the failure of the drum. This resulted to eruption from the top of the drum stack and the eruption fell to the floor and accumulated to vapour cloud, after few minutes this vapour cloud exploded, source of ignition was assumed to be the diesel pick-up truck. This explosion resulted to the death of 15 workers and also left over 180 workers injured. 50 large chemical storage tanks were destroyed and some vehicles and trailers were burnt completely [1].

Finally, BP was compelled to pay about 50.6 million dollars on compensation and clean-up of the mess [2].

Hazards that led to the accident and brief description on how each caused the accident:

The hazards that led to the accident include;

(a) Flammable hydrocarbon liquids
(b) Level indicator on the raffinate
(c) Standby high level alarms on the raffinate tower
(d) Liquid control valve on the tower
(e) Tower pressure valves
(f) Emergency release valves
(g) High level alarm at the blow down drum

(h) Diesel pick-up truck

(a) Level indicator on the raffinate tower; analysing this incidence, the level indicator was the major contributor and initiator to this accident, its failure and wrong indication of the actual liquid level led to the liquid build up in the tower and this initiated the whole unit failure.

(b) Redundant high level alarm on the tower; the second (redundant) alarm that failed to activate deceived the operators the more, if it had sounded, they would maybe walk through the process and hopefully would have found out that the control valve was locked and that the level indicator was misleading.

(c) Liquid Control Valve; this contributed to the build-up of liquid level and pressure, if it had opened, some liquid would have gone out maybe to the storage tank and help reduced the alarming build up in the tower.

(d) Tower Pressure Valves; if it hadn't failed, would have opened to help reduce the pressure that was built up as a result of the liquid.

(e) Tower Emergency Release Valves; these release valves failed and as a result the flammable liquid that caused this explosion was released and the blow down drum was flooded.

(f) Flammable hydrocarbon liquids; this was the actual explosion substance, if hadn't released, no explosion would have occurred.

(g) High level alarm at the blow down drum; the failure of this alarm led to the complete failure of the drum which released the flammable vapour. Maybe if hadn't failed, operators would have saved the drum from failing.

(h) Diesel pick-up truck; this was assumed to be the source that ignited the flammable liquid, its presence and that of the highly flammable liquids contributed greatly to the explosion incidence. Assuming no ignition source, the presence of flammable liquids only is not enough to cause an explosion.

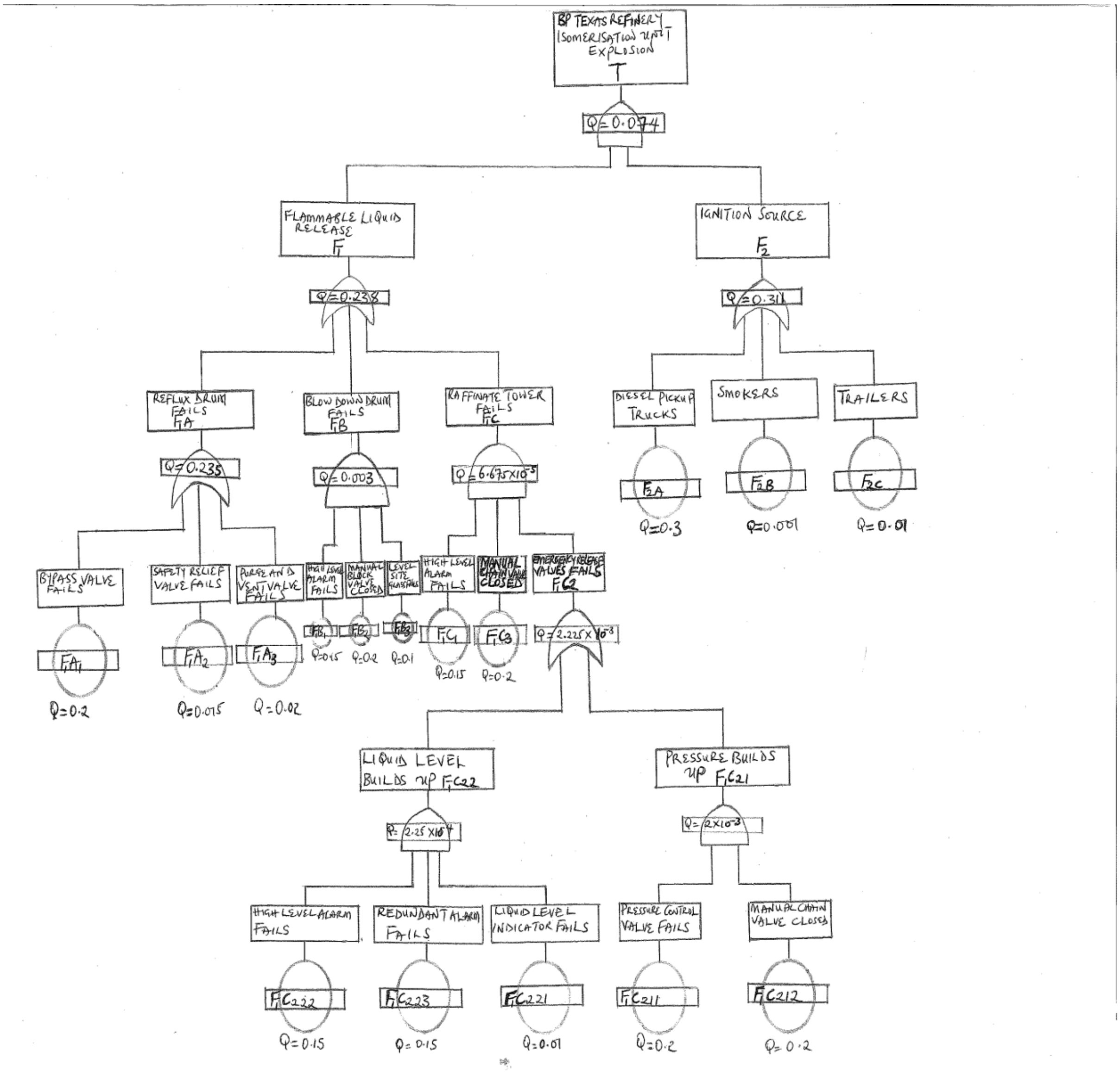

Figure 1: FTA

The logic leading to the accident:

(a) Pressure build-up in the tower; there was a pressure build-up in the raffinate tower and this happened because **BOTH** the pressure control valve failed **AND** the manual chain valve was left closed. The logic expression to this is given as;

$\mathbf{F_{1C21} = F_{1C211} \cap F_{1C212}}$

(b) Liquid level builds up in the tower; the volume of the flammable liquid in the tower rose to more than the designed level. This happened as a result of **BOTH** the failure of the liquid level indicator **AND** the failure of the High level alarm **AND** the failure of the redundant alarm. The logical expression to this is;

$\mathbf{F_{1C22} = F_{1C221} \cap F_{1C222} \cap F_{1C223}}$

(c) The emergency release valves on the tower failed; the emergency release valves on the tower failed and opened, causing liquid to build up at the blow down drum which was eventually flooded. The failure of the emergency release valves was as a result of the pressure build up in the tower **OR** the liquid level build-up. The logical expression to this is given as;

$\mathbf{F_{1C2} = F_{1C21} \cup F_{1C22}}$

(d) Raffinate Tower failed and allowed flammable liquids to escape; this failure was as a result of the failure of the high level alarm on the tower **AND** the failure of the emergency release valve **AND** the failure of manual chain valves which was left closed. The logical expression is given overleaf as:

$\mathbf{F_{1C} = F_{1C1} \cap F_{1C2} \cap F_{1C3}}$

(e) Blow down drum failed; the collapse and the failure of the blow down led to the flammable vapour dropping at the floor of the site. This component failure was as a result of the failure of the high level alarm at the blow down drum **AND** the failure of the level site glass mounted on the drum **AND** the failure of the manual block valve which was left closed. The logical expression to this failure is given as;

$\mathbf{F_{1B} = F_{1B1} \cap F_{1B2} \cap F_{1B3}}$

(f) Failure of reflux drum; the failure of the reflux drum was as a result of the failure of the reflux bypass valve **OR** the failure of the safety relief valve **OR** the failure of the purge and vent valve. The logical expression to this is given as;

$\mathbf{F_{1A} = F_{1A1} \cup F_{1A2} \cup F_{1A3}}$

(g) Flammable liquid dropped to the ground; this was the hazard that led to the explosion. The sources of this hazard could be as a result of the failure of the reflux drum **OR** the failure of the blow down drum **OR** the failure of the raffinate splitter tower. The logical expression to the release of this hazard is given as;

$\mathbf{F_1 = F_{1A} \cup F_{1B} \cup F_{1C}}$

(h) Ignition source; this hazard reacted with the flammable liquid on the floor causing a fatal explosion of the refinery. The source of this ignition could be; Diesel pick-up truck at the site **OR** the trailers packed at the site **OR** a staff smoking around the premises. The logic leading to this is expressed as;

$\mathbf{F2 = F_{2A} \cup F_{2B} \cup F_{2C}}$

(i) BP Refinery Isomerisation Unit Explosion; this is the top event of the accident. It was as a result of BOTH the flammable liquid on the floor refinery site **AND** a source of ignition both of which reacted and led to the explosion of the isomerisation unit of the refinery. The logical expression to this TOP event is given as;

$\mathbf{T = F_1 \cap F_2}$

$\mathbf{= (F_{1A} \cup F_{1B} \cup F_{1C}) \cap (F_{2A} \cup F_{2B} \cup F_{2C})}$

$\mathbf{= [(F_{1A1} \cup F_{1A2} \cup F_{1A3}) \cup (F_{1B1} \cap F_{1B2} \cap F_{1B3}) \cup (F_{1C1} \cap F_{1C2} \cap F_{1C3})] \cap (F_{2A} \cup F_{2B} \cup F_{2C})}$

$\mathbf{= [(F_{1A1} \cup F_{1A2} \cup F_{1A3}) \cup (F_{1B1} \cap F_{1B2} \cap F_{1B3}) \cup (F_{1C1} \cap (F_{1C21} \cup F_{1C22})) \cap F_{1C3}] \cap (F_{2A} \cup F_{2B} \cup F_{2C})}$

$= [(F_{1A1} \cup F_{1A2} \cup F_{1A3}) \cup (F_{1B1} \cap F_{1B2} \cap F_{1B3}) \cup (F_{1C1} \cap (F_{1C211} \cap F_{1C212})) \cup (F_{1C221} \cap F_{1C222} \cap F_{1C223}) \cap F_{1C3}] \cap (F_{2A} \cup F_{2B} \cup F_{2C})$

The above equation, gives the overall logical expression to the TOP EVENT (T).

Things that can be done (Recommendations) to prevent future failure based on the FTA

- Owing to the fact that these are mechanical equipment designed by human beings, they are prone to failure due to human error. The operators on this site shouldn't rely solely on the readings from the level indicators as these can be misleading atimes. The operators should be able to walk the line ups, that is, walk round all the facilities and inspect the process flow manually from time to time instead of continuous 100% over reliance on instrumentation.

- Some mechanical instruments like the alarms (high level, pressure, redundant, etc.) should be inspected like once in a week in order to ascertain that they're still working as designed. From time to time the operators can test run the alarms to make sure their sounds are still proper and as effective as their design functions.

- Adequate start up procedures must be followed as lack of it contributed to the loss of process control [3] and inspections for corroded components should be done from time to time, say once a month.

- The operators should make sure that all manual valves for emergency outflow of liquids are open and this can be done by manually inspecting the valves often.

- Sources of ignition must in no case, under no circumstances be kept or brought near a refinery site, all trucks must be kept at a reasonable distance safe enough not to cause explosion.

- Shut down and preventive maintenance should be carried out occasionally to ensure that all instruments and equipment work as designed.

Quantifying the FTA (with subsequent probability calculations leading to the probability of the top event):

From my research and the literature I consulted on Energy Industry accident events with BP Refinery Isomerisation unit explosion as a case study [4], the probabilities of the Basic Events/Contributors that led to the TOP EVENT (isomerisation unit explosion) have been estimated below to be [4];

- $P(F_{1A2})$ = (probability of failure of safety relief valve) = 0.015

- $P(F_{1A3})$ = (probability of failure of purge and vent valve) = 0.0
- $P(F_{1A1})$ = (probability of failure of reflux bypass valve) = 0.2

- ❖ $P(F_{2B})$ = (probability of smokers at the refinery premises) = 0.001
- ❖ $P(F_{2C})$ = (probability of packed trailers at the site) = 0.01
- ❖ $P(F_{2A})$ = (probability of diesel pick-up truck) = 0.3
- ❖ $P(F_{1B3})$ = (probability of failure of level site glass) = 0.1
- ❖ $P(F_{1B1})$ = (probability of failure of high level alarm) = 0.15
- ❖ $P(F_{1B2})$ = (probability of failure of manual block valve left closed) = 0.2
- ❖ $P(F_{1C211})$ = (probability of failure of pressure control valve) = 0.01
- ❖ $P(F_{1C221})$ = (probability of failure of liquid level indicator) = 0.01
- ❖ $P(F_{1C1})$ = (probability of failure of high level alarm) = 0.15
- ❖ $P(F_{1C3})$ = (probability of failure of manual chain valves left closed) = 0.2
- ❖ $P(F_{1C212})$ = (probability of failure of manual chain valve left closed) = 0.2
- ❖ $P(F_{1C222})$ = (probability of failure of high level alarm) = 0.15
- ❖ $P(F_{1C223})$ = (probability of failure of redundant alarm) = 0.15

Having estimated the probabilities of these Basic Events, calculating the probabilities of other failure events up to the TOP event, we have;

- ❖ $P(F_{1C22})$ = (probability of liquid build up) = $P(F_{1C221} \cap F_{1C222} \cap F_{1C223})$
  $= P(F_{1C221}) \times P(F_{1C222}) \times P(F_{1C223})$
  $= 0.01 \times 0.15 \times 0.15 = \mathbf{2.25 \times 10^{-4}}$

- ❖ $P(F_{1C21})$ = (probability of pressure build up) = $P(F_{1C211} \cap F_{1C212})$
  $= P(F_{1C211}) \times P(F_{1C212})$
  $= \mathbf{0.01 \times 0.2 = 2 \times 10^{-3}}$

- ❖ $P(F_{1C2})$ = (probability of failure of emergency release valve) = $P(F_{1C21} \cup F_{1C22})$

  $= P(F_{1C21}) + P(F_{1C22})$……(for small failure probability)
  $= (2 \times 10^{-3}) + (2.25 \times 10^{-4})$
  $= \mathbf{2.225 \times 10^{-3}}$

- ❖ $P(F_{1C})$ = (probability of failure of raffinate splitter tower)
  $= P(F_{1C1} \cap F_{1C2} \cap F_{1C3})$
  $= P(F_{1C1}) \times P(F_{1C2}) \times P(F_{1C3})$
  $= 0.15 \times 2.225 \times 10^{-3} \times 0.2$
  $= \mathbf{6.675 \times 10^{-5}}$

- ❖ $P(F_{1B})$ = (probability of failure of blow down drum)

$= P(F_{1B1} \cap F_{1B2} \cap F_{1B3}) = P(F_{1B1}) \times P(F_{1B2}) \times P(F_{1B3})$
$= 0.15 \times 0.2 \times 0.1 = \mathbf{3x10^{-3}}$

- ❖ $P(F_{1A})$ = (probability of failure of reflux drum)
  $= P(F_{1A1} \cup F_{1A2} \cup F_{1A3})$
  $= P(F_{1A1}) + P(F_{1A2}) + P(F_{1A3})$……(for small failure probability)
  $= 0.2 + 0.015 + 0.02$
  = 0.235

- ❖ $P(F_1)$ = (probability of flammable liquid on the ground)
  $= P(F_{1A} \cup F_{1B} \cup F_{1C})$
  $= P(F_{1A}) + P(F_{1B}) + P(F_{1C})$……(for small failure probability)
  $= 0.235 + (3x10^{-3}) + (6.675x10^{-5})$
  = **0.238**

- ❖ $P(F_2)$ = (probability of ignition source)
  $= P(F_{2A} \cup F_{2B} \cup F_{2C})$
  $= P(F_{2A}) + P(F_{2B}) + P(F_{2C})$……(for small failure probability)
  $= 0.3 + 0.001 + 0.01$
  = **0.311**

- ❖ **P(T)** = (probability of the **TOP EVENT**)
  $= P(F_1 \cap F_2)$
  $= P(F_1) \times P(F_2)$
  $= 0.238 \times 0.311$
  = **0.074**

Prioritising the contributors that led to the accident:

Having consulted materials on prioritising BASIC EVENTS/CONTRIBUTORS to an accident, I chose to use Risk Achievement Worth (RAW) method. The formula for RAW is given as; $BE = P_1/P_R$ [5].
Where BE = Basic Event, P_1 = probability of the top event given that P(BE) = 1, P_R = probability of the reference top event. The P_1 values for the various Basic Events are calculated by sensitivity analysis method. The Prioritisation is then done using the values of the P_1/P_R , the basic event with the highest P_1/P_R value takes the priority 1, the one with the second highest value of P_1/P_R, takes priority 2 and it continues like that to the least priority.

For my case, my P_R = P(T) = 0.074= probability of the top event, I've calculated the P_1 values for all the Basic Events by assuming the probability of each Basic Event to be 1(has failed) each one at a time and noting the effect of these on the probability of the top event, the corresponding new values of the probability of the top event when these Basic Events were taken to be of the value 1 is known as the P_1.

I calculated the P_1 values of the basic events by sensitivity analysis method using excel spreadsheet and my results are shown in the table below;

Table 1; Risk Achievement Worth (P_1/P_R) for the Basic Events

Contributors (Basic Events)	**P_1Values(Probability of top event when BE probability=1)**	**P_1/P_R (P_R=0.074)**
F_{1A1} (failure of reflux bypass valve)	0.3228	4.3599
F_{1A2} (failure of safety relief valve)	0.3804	5.1378
F_{1A3} (failure of purge and vent valve)	0.3788	5.1162
F_{1B1} (failure of high level alarm)	0.0793	1.0716
F_{1B2} (failure of manual block valve left closed)	0.0778	1.0514
F_{1B3} (failure of level site glass)	0.0824	1.1135
F_{1C1} (failure of high level alarm)	0.0742	1.0027
F_{1C3} (failure of manual chain valve left closed)	0.0741	1.0014
F_{1C211} (failure of pressure control valve)	0.0759	1.0257
F_{1C212} (failure of manual chain valve left closed)	0.0741	1.0014
F_{1C221} (failure of liquid level indicator)	0.0742	1.0027
F_{1C222} (failure of high level alarm)	0.0741	1.0014
F_{1C223} (failure of redundant alarm)	0.0741	1.0014
F_{2A} (presence of a diesel pick-up truck at the site)	0.2407	3.2527
F_{2B} (smokers around the refinery site)	0.3119	4.2149
F_{2C} (packed trailers present near the site)	0.3097	4.1829

With the values of the P1/PR for each Basic Event in the table above, we can now prioritise the contributors that led to the isomerisation unit explosion and hence give recommendations on how to avoid or mitigate the occurrence of each contributor.

The prioritisation table for the contributors with recommendations on how to avoid or mitigate their occurrence is given below;

Table 2; The Contributors Prioritisation from the Highest Contributor to the Least

Priority # (from top to bottom)	Contributors (Basic Events)	P_1/P_R Value	Recommendations
1	$\mathbf{F_{1A2}}$ (failure of safety relief valve)	5.1378	Constant inspection for corrective/preventive maintenance.
2	$\mathbf{F_{1A3}}$ (failure of purge and vent valve)	5.1162	Constant inspection for corrective/preventive maintenance.
3	$\mathbf{F_{1A1}}$ (failure of reflux bypass valve)	4.3599	Constant inspection for corrective/preventive maintenance.
4	$\mathbf{F_{2B}}$ (smokers around the refinery site)	4.2149	On no account should anybody smoke around the premises of refinery
5	$\mathbf{F_{2C}}$ (packed trailers present near the site)	4.1829	Ignition sources like this should be kept far away from the refinery site.
6	$\mathbf{F_{2A}}$ (presence of a diesel pick-up truck at the site)	3.2527	Ignition sources like this should be kept far away from the refinery site
7	$\mathbf{F_{1B3}}$ (failure of level site glass)	1.1135	Constant inspection for corrective/preventive maintenance.
8	$\mathbf{F_{1B1}}$ (failure of high level alarm)	1.0716	Constant inspection for corrective/preventive maintenance.
9	$\mathbf{F_{1B2}}$ (failure of manual block valve left closed)	1.0514	Routine inspection to make sure such valves are left opened.
10	$\mathbf{F_{1C211}}$ (failure of pressure control valve)	1.0257	Constant inspection for corrective/preventive maintenance.
11	$\mathbf{F_{1C1}}$ (failure of high level alarm)	1.0027	Constant inspection for corrective/preventive maintenance.
11	$\mathbf{F_{1C221}}$ (failure of liquid level indicator)	1.0027	Constant inspection for corrective/preventive maintenance.
12	$\mathbf{F_{1C3}}$ (failure of manual chain valve left closed)	1.0014	Routine inspection to make sure such valves are left opened
12	$\mathbf{F_{1C212}}$ (failure of manual chain valve left closed	1.0014	Routine inspection to make sure such valves are left opened
12	$\mathbf{F_{1C222}}$ (failure of high level alarm)	1.0014	Constant inspection for corrective/preventive maintenance.
12	$\mathbf{F_{1C223}}$ (failure of redundant alarm)	1.0014	Constant inspection for corrective/preventive maintenance.

The table above shows the level of contribution of each Basic Event to the explosion of BP Texas Isomerisation Unit Explosion, the failure of the safety relief valve at the reflux drum was the highest contributor to this incidence, followed by the failure of the purge and vent valve and the failure of the redundant alarm has been seen to be the least contributor to the explosion incidence.

REFERENCES

[1] U.S. Chemical Safety and Hazard Investigation Board. BP Texas Refinery (Isomerisation Unit) Explosion Animation Video. 2005

[2] Occupational health and safety administration. BP history fact sheet. 2009.

[3] Michael P. Broadribb. Lessons from Texas City, A Case History. 2006; Available at: http://www.gulfcoastdisaster.com/etc/deepwater/files/website/Lessons%20Learned%20-%20Broadribb%20-%20CCPS%20Conference.pdf.

[4] Maryam Kalantarnia, Faisal Khan, Kelly Hawboldt. Modelling of BP Texas City refinery accident using dynamic risk assessment approach. 2009; 9.

[5] International Atomic Energy Agency. PSA Quantification; Analysis of Results.