A Tale of Two Plants

Using LOPA for SIL Assignment

CF Industries™

BLUEFIELD PROCESS SAFETY

Mike Schmidt bio

- **Principal of Bluefield Process Safety**
- **Formerly an Emerson SIS consultant**
- **Joined Union Carbide in 1977**
- **Began work in process safety, following tragedy in Bhopal in 1984**
- **Joined faculty at Missouri S&T in Rolla in 2009, teaching on safety and risk**
- **Work includes**
  - **Facilitating PHAs, LOPAs, RTC establishment**
  - **SIS conceptual design**
  - **PSM compliance**

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Presented by

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Introduction

- **Should SIFs with fixed SIL assignment be assigned to certain type of installations?**
- **Terra Industries**
  - **Port Neal, Iowa**
  - **Yazoo City, Mississippi**
- **Ammonium Nitrate Pumps**

Ammonium nitrate pumps

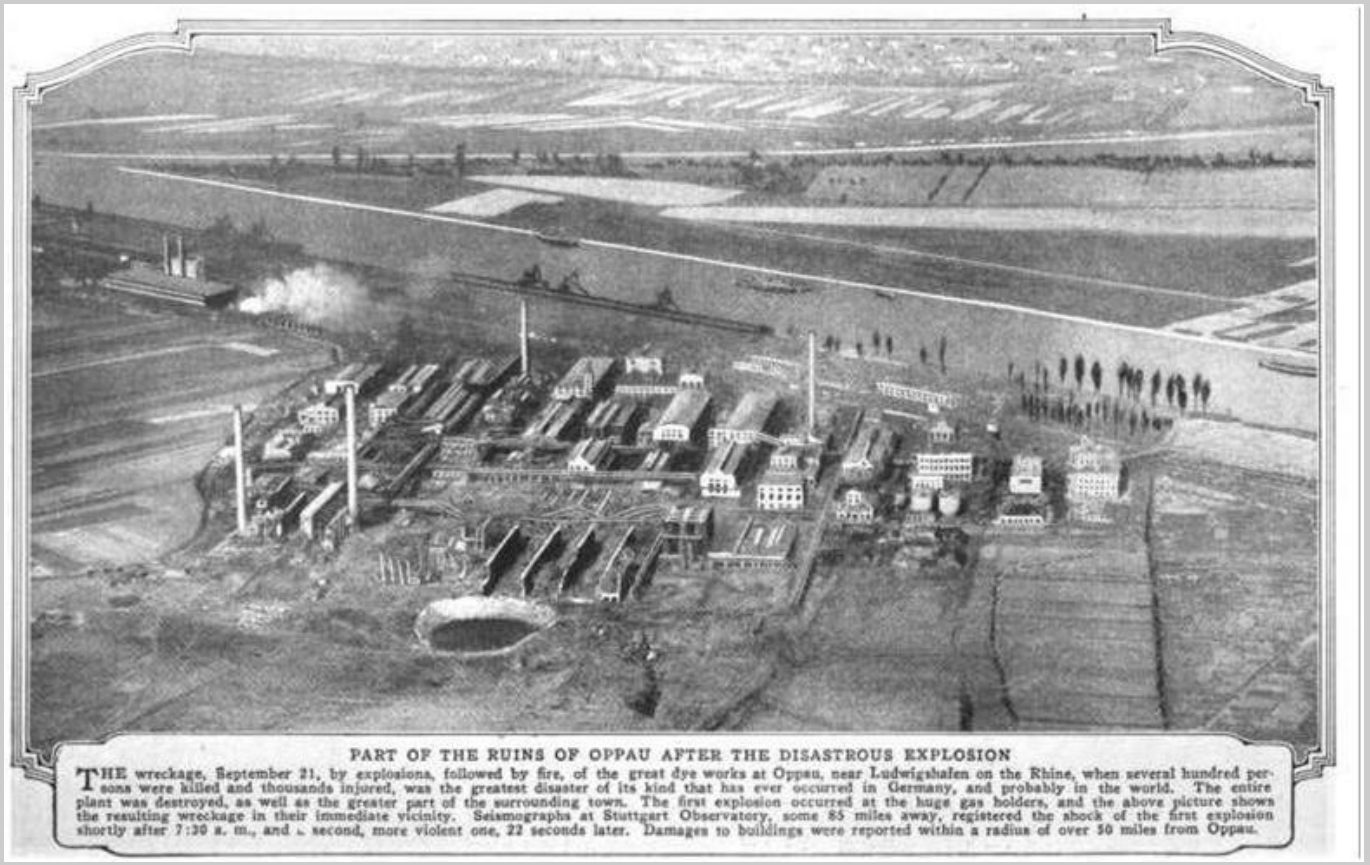
- **Weak AN liquor – 20 to 60%**
- **AN Solution – 60 to 85%**
- **AN Melt – 97.5 to 99.9%**

- **Typically centrifugal pumps**

AN production disasters

- **Oppau, Germany – 561 fatalities**
  Wed, 21-Sep-1921, 7:32 am
- **Nixon, New Jersey – 18 fatalities**
  Sat, 1-Mar-1924, 11:30 am
- **Tessenderlo, Belgium – 189 fatalities**
  Wed, 29-Apr-1942, 11:27 am
- **Papua, New Guinea – 11 fatalities**
  Tue, 02-Aug-1994, 9:45 am
- **Port Neal, Iowa – 4 fatalities**
  Tue, 13-Dec-1994, 6:13 am
- **Toulouse, France – 31 fatalities**
  Fri, 21-Sep-2001, 10:15 am

BASF disaster in Oppau



PART OF THE RUINS OF OPPAU AFTER THE DISASTROUS EXPLOSION

THE wreckage, September 21, by explosions, followed by fire, of the great dye works at Oppau, near Ludwigshafen on the Rhine, when several hundred persons were killed and thousands injured, was the greatest disaster of its kind that has ever occurred in Germany, and probably in the world. The entire plant was destroyed, as well as the greater part of the surrounding town. The first explosion occurred at the huge gas holders, and the above picture shows the resulting wreckage in their immediate vicinity. Seismographs at Stuttgart Observatory, some 85 miles away, registered the shock of the first explosion shortly after 7:30 a. m., and a second, more violent one, 22 seconds later. Damages to buildings were reported within a radius of over 50 miles from Oppau.

From Popular Mechanics, 1921, public domain

Terra disaster in Port Neal

From USEPA Accident Investigation Report, 1994, public domain

Hazards of ammonium nitrate

- **Toxic exposure**

  $NH_4NO_3 \leftrightarrow NH_3{}_{(gas)} + HNO_3{}_{(gas)}$ - heat

  $NH_4NO_3 \rightarrow N_2O{}_{(gas)} + 2H_2O{}_{(gas)}$ + heat

- **Fire**

  $2NH_4NO_3 \rightarrow 2N_2 + O_2 + 4H_2O$

- **Explosion**

  $2NH_4NO_{3(liq)} \rightarrow N_{2(gas)} + 2NO_{(gas)} + 4H_2O_{(gas)}$

  $2NH_4NO_{3(liq)} \rightarrow 2N_{2(gas)} + O_{2(gas)} + 4H_2O_{(gas)}$

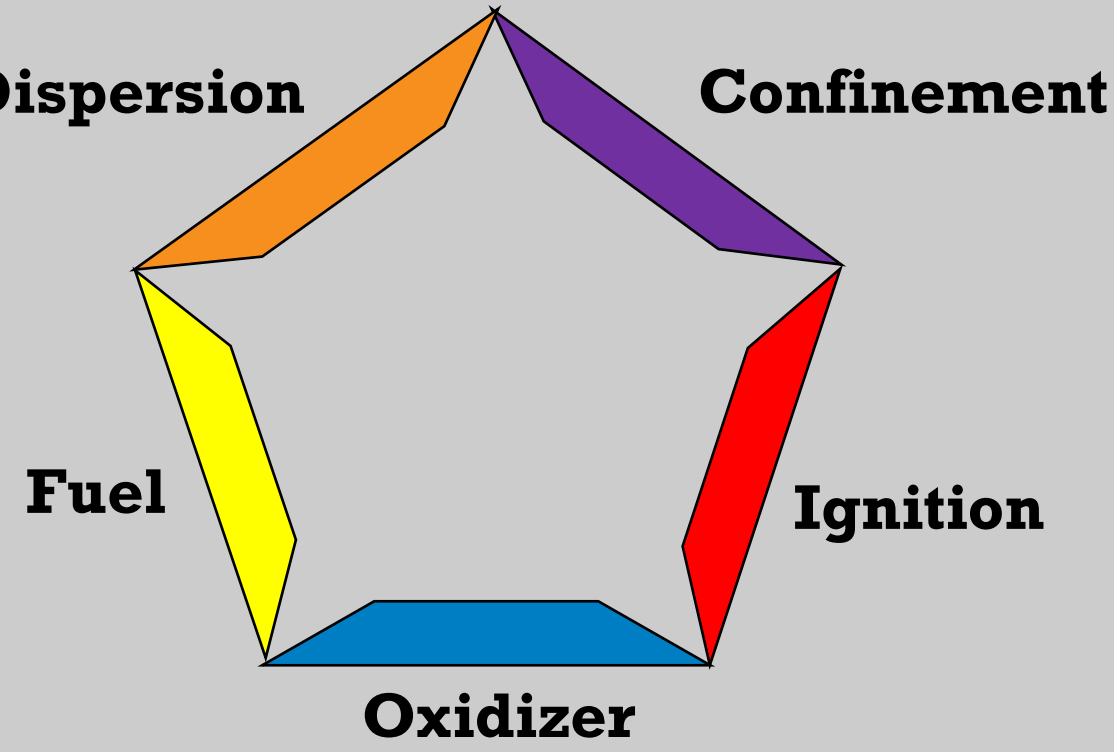
Stability of ammonium nitrate

Decreases with

- **Increased time**
- **Higher temperature**
- **Increased contamination**
- **Confinement**
- **Higher concentration**
- **Acidic pH**
- **Lower density**

The Explosion Pentagon

- **Combustion based explosion**



Remains of a pump incident

Residual risk

Residual risk, hence SIL assignment, depends on

- **Risk Tolerance Criteria (RTC)**
- **Event impact (consequences)**
- **Type and frequency of initiating cause**
- **Enabling conditions**
- **Other IPLs already in place**

Risk tolerance criteria

Safety Consequences	Severity
≥ 10 fatalities/event	A
≥ 1 fatality/event	B
≥ 1 disabling injury/event	C
≥ 1 recordable injury/event	D
≥ 1 first aid injury/event	E
< 1 first aid injury/event	F

Consequences

- One plant's team determined the probable impact in all cases to be one or more disabling injuries
- The other plant's team allowed different probable impacts, depending on the hazard
  - One or more disabling injuries
  - One or more fatalities
  - Ten or more fatalities

Initiating causes – ongoing

Initiating Cause	Frequency
Pump trip	1
Unit trip	1
BPCS function failure	0.1
Control valve fails in direction of design	0.1
Heat tracing failure	0.1

Opportunity-based causes

Initiating Cause	Probability
High-stress, non-routine	1
Routine or low-stress	0.1
Failure to execute written procedure	0.01
Failure to execute procedure including independent review	0.001

Enabling conditions

Standard

- **Time at risk**
- **Occupancy factor**
- **Ignition probability**
- **Vulnerability**

Others

- **Weather conditions**
- **Operating levels**
- **Sensitizing contaminants present**

Occupancy Factors

Occupancy	Factor
Personnel always present	1
In area 8 hr, 200 day/yr	0.18
In area 5 min/hr	0.08
In area 5 min/2 hr	0.04
In area 2 min/hr	0.03
In area 1 hr/month	0.0014

IPLs used in these projects

IPL	PFD_{AVG}
Procedural controls	0.1
BPCS Functions	0.1
Heat tracing	0.1
Operator response to alarm or field condition, 20 min buffer	0.1
Operator response to field condition, 40 min buffer	0.01
Kickback (minimum flow) line	0.01
Relief valve	0.01
Self-draining pump	0.1

RRF distribution for AN pumps

Required RRF	Pumps
❖ No additional required	50
❖ 1 < RRF ≤ 10	25
❖ 10 < RRF ≤ 100	15
❖ 100 < RRF ≤ 1,000	7
❖ 1,000 < RRF ≤ 10,000	5
Total number of pumps	102

New risk reduction measures

IPL	Pumps
Non-SIL hi temp shutdown	25
SIL 1 hi temp shutdown	20
SIL 2 hi temp shutdown	4
Non-SIL lo level shutdown	8
SIL 1 lo level shutdown	2
Kick back line	12
Total number of measures	71

Conclusions

SIL assignment is not cookie-cutter

- **What RTC is used?**
- **What are the initiating causes?**
- **What is the frequency of those initiating causes?**
- **What is the consequence of the event?**
- **What is the probability of enabling conditions?**
- **What safeguards are already installed? Which of them are IPLs?**