PRD Model Update

API RBI User Group Meeting
February 23 -24, 2005

PROPRIETARY INFORMATION
For Authorized Company Use Only

API RBI PRD Module

- Background
- Methodology
- Probability of Failure
- Consequence of Failure
- Calculation of Risk
- Direct Link to Fixed Equipment
- Case Studies

API RBI PRD Module

- Background
  - E^{2}G spent most of 2004 developing methodology and programming in parallel to development of the new consequence model
  - API PRD Module Technical Write-up is complete and is currently being balloted
  - Methodology has been incorporated into Rev 6.0 of the API RBI software
  - Methodology is currently being used by E^{2}G on several pilot studies, very realistic results

API RBI PRD Module

- Methodology
  - Highly Quantitative
  - Risk for PRDs are calculated for two failure modes
  - Fail to Open (FAIL)
    - PRD does not open on demand during an overpressure scenario (fire, blocked discharge, CV failure, Loss of Cooling, Power failure, etc.)
    - Over pressures can be well over normal operating, for some scenarios burst pressure (≈ 4 x Design pressure)
    - Evaluate loss of containment (leaks or ruptures) from the protected equipment at the overpressure
    - Includes repair costs of equipment, personnel injury, environmental and production losses
  - Leakage Failure (LEAK)
    - PRD leaks in-service
    - Considers cost of lost fluid inventory, repair costs, production losses if downtime is required to repair PRD
  - RISK = POF x COF + POL x COL

API RBI PRD Methodology

- Probability of Failure

$$POF = POFOD \times DR \times (GFF \times DF)_{OP}$$

  - POF is probability of PRD failure to open during emergency situations causing an overpressure situation in the protected equipment resulting in loss of containment (failures/year)
  - POFOD is the probability of the PRD failing to open on demand (failure/demand)
  - DR is the demand rate on the PRD or how often an overpressure situation arises that causes a demand on the valve (demands/year)
  - (GFF X DF) is the probability of failure (loss of containment) from the vessel in its current damaged state

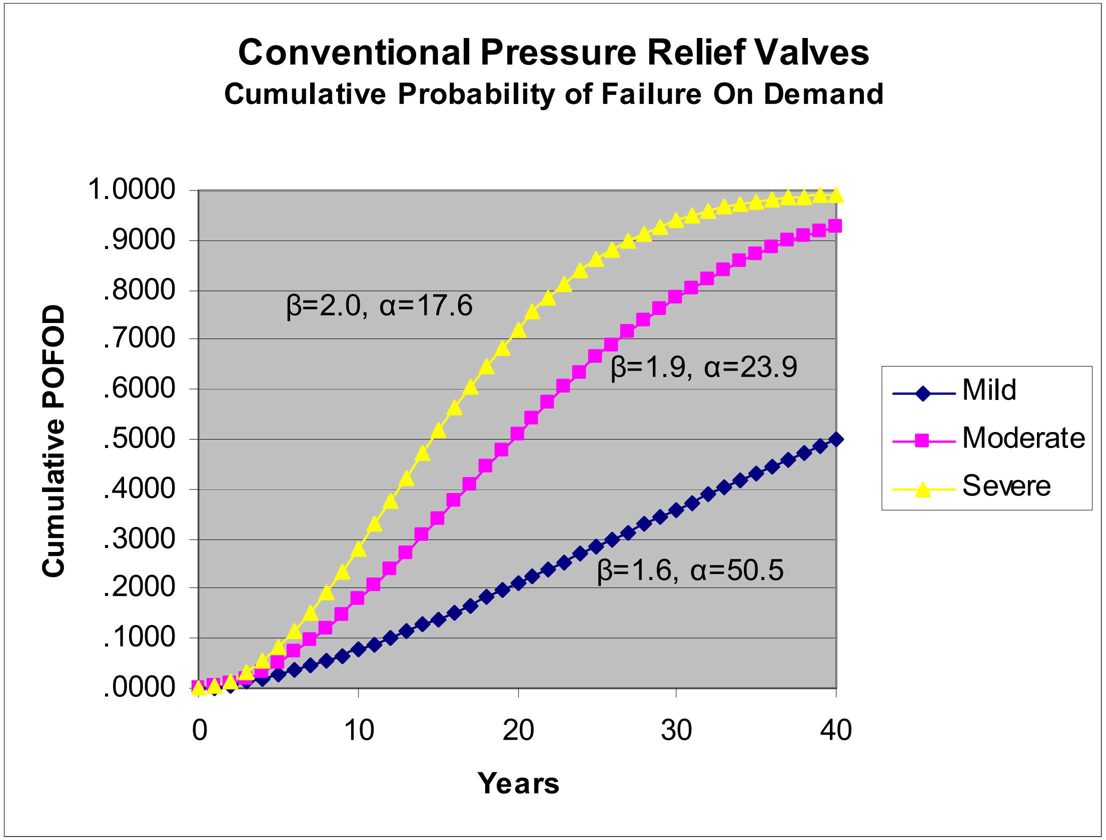
- Probability of Leakage
  - POL has units of (per year)$^{-1}$ since we are concerned with leak during normal operation *at overpressure*

API RBI PRD Methodology

- Probability of Failure on Demand (POFOD)
  - Use E^2G Failure Database
  - Contains about 5000 data points from actual in-shop bench tests
  - Tracks FTO and LEAK data for Conventional, Balanced, Pilot-Operated PRVs and Rupture Disks
  - Database for FTO case includes:
    - Stuck or Fails to Open (FTO)
    - Includes Valve Partially Opens (VPO)
    - and Opens Above Set Pressure (OASP)
  - Database for LEAK case includes:
    - Leakage Past Valve (LPV),
    - Spurious/Premature Opening (SPO)
    - and Valve Stuck Open (VSO)
  - Need more Pilot and RD data
  - Tracks effects of temperature, fluid severity, pulsing service, pipe vibration
  - FTO is defined as failure to open at 1.3 times the set pressure
  - LEAK is qualified as minor, moderate and stuck open, based on where the PRV started to leak in relation to set pressure on the bench test

API RBI PRD Methodology

- Actual Failure Data for Default Mild, Moderate and Severe Services



API RBI PRD Module

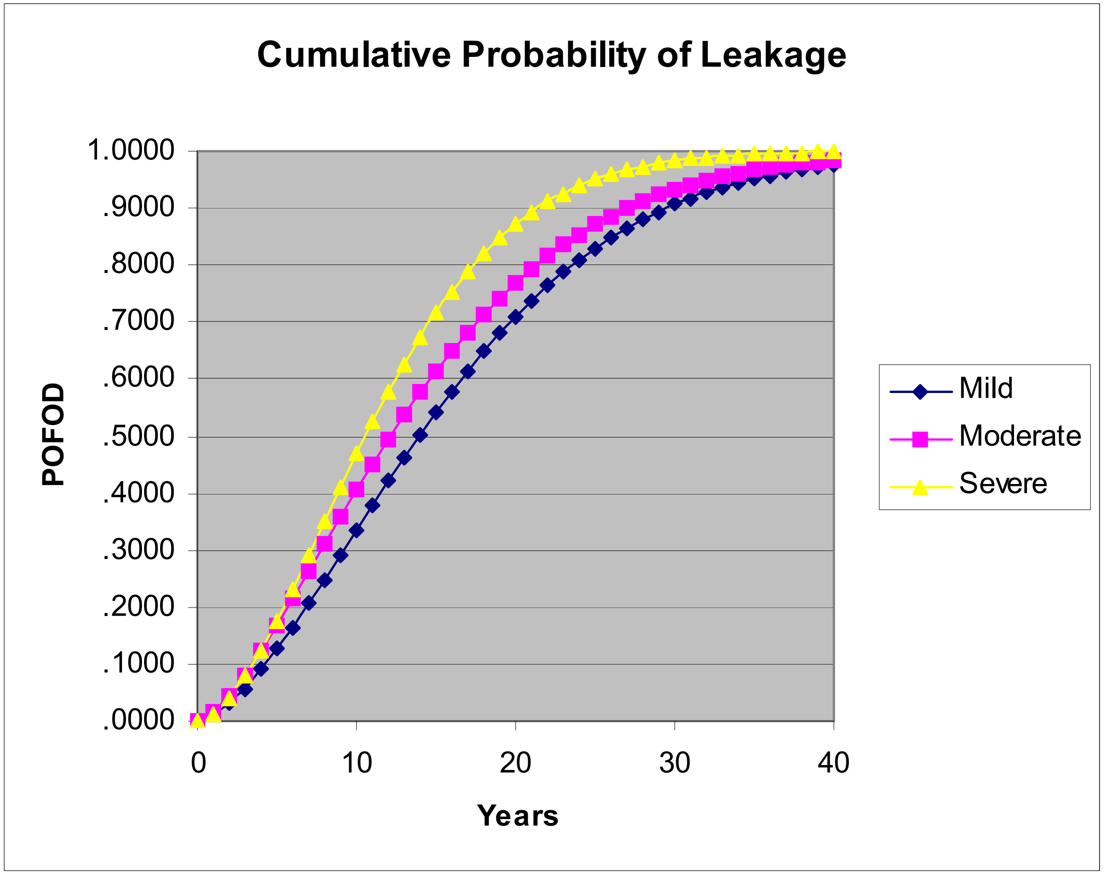
- Actual Failure Database for Default Mild, Moderate and Severe Services

TABLE 6.1 CATEGORIES OF PRD SERVICE SEVERITY

Service	Description
Mild	Few or no early failures. Clean, filtered hydrocarbon products at moderate temperature. No aqueous phase present. Low in sulfur and chlorides. Failure is characterized by a long (20 years) MTBF. Failure is strongly characterized as a wear out type of failure, in which the failure finally comes due to an accumulation of damage over a long period of time.
Moderate	There is a significant chance of failure before the 10 year MTBF. Hydrocarbons that may contain some particulate matter. A separate aqueous phase may be present, but is a minor component, however, clean, filtered and treated water may be included in this category. Some sulfur or chlorides may be present. Temperatures of up to 500 F. Failure is weakly characterized as a wear out type of failure, in which the failure comes due to an accumulation of damage.
Severe	There is a significant chance of early failure before the 5 year MTBF. Hydrocarbons that are processed at temperatures above 500 F with significant tendency to fouling. Sulfur and chlorides may be high. Monomers processed at any temperature that can polymerize are in this group as well. Sometimes included are aqueous solutions of process water, including cooling water. Failure is characterized as a random type of failure, in which the failure can occur due to a variety of mechanisms such as corrosion or plugging.

API RBI PRD Methodology

- Actual Leakage Data for Default Mild, Moderate and Severe Services



API RBI PRD Module

- Use Actual Failure Database for Default Mild, Moderate and Severe Services

	Fluid Service Classification	Fluid Service Classification
Fluid	Mild, Moderate, or Severe Pass/ Fail Data	Mild, Moderate, or Severe Leak Data
H_2S	Severe	Moderate
Crude / Heavy HC	Severe	Mild
Rich / Lean Amine	Severe	Mild
Chemical- Liquid	Severe	Mild
Cooling Water	Severe	Mild
Corrosive HC Vapor	Severe	Moderate
Corrosive Liquid	Severe	Severe
Lube, Cycle and Seal Oils	Moderate	Moderate
Chemical - Gas	Moderate	Moderate
Intermediate HC	Moderate	Moderate
Air	Moderate	Mild
HC Vapor	Mild	Moderate
Process Water	Mild	Moderate
LPG/ NGL	Mild	Mild
BFW/ Condensate	Mild	Severe
Steam	Mild	Severe
Product HC	Mild	Moderate

API RBI PRD Methodology

- Probability of Failure on Demand - POFOD (Failures/demand)
  - Default Weibull failure (POFOD) curves are chosen based on the fluid severity (Mild, Moderate, Severe) selected by the user
  - User can supply own Weibull parameters if desired
  - Default curves are then adjusted based on the knowledge gained from the historical inspection records for each PRD

API RBI PRD Methodology

-- Inspection Updating Results --

PRD Installation Date. . . . . DATEINST =	1-JAN-1988	
Default Alpha Parameter - FTO. . . . . ALPHA =	18.8000	years
Default Beta Parameter - FTO. . . . . BETA =	1.0000	
Default Probability of Failure on Demand. PPOFOD_DEF =	0.1476	
Default Alpha Parameter - Leakage. . . . . . ALPHALK =	7.9200	years
Default Beta Parameter - Leakage. . . . . . BETALK =	1.3000	
Default Probability of Leakage. . . . . . PPOL_DEF =	0.2468	

-- Historical Inspection Summary --

Date of Inspection	Actual Duration	Inspect. Effect.	Result (P/F)	Leak (Y/N)	Ohaul (Y/N)	Ohaul Durtn	Updtd Alpha	Updtd POFOD	Updtd Alplk	Updtd POL
1-JAN-1991	3.00	A	PASS	NO	YES	3.0	19.1	0.14	8.3	0.23
1-JAN-1994	3.00	A	FAIL	NO	YES	3.0	11.9	0.22	8.3	0.23
1-JAN-1997	3.00	A	PASS	NO	NO	3.0	12.3	0.21	8.7	0.22
1-JAN-2000	3.00	A	FAIL	NO	YES	6.0	10.7	0.42	8.7	0.46
1-JAN-2003	3.00	A	PASS	NO	YES	3.0	11.2	0.23	9.0	0.21

API RBI PRD Methodology

- Demand Rate - DR (demands/year)
  - The methodology recognizes the fact that the PRD is not needed the majority of the time that is in-service, it is only needed during an overpressure event (fire, loss of power, blocked discharge, etc.)
  - These overpressure events are rare, demand rates are typically on the order of 1/10 years but some are extremely rare, such as fire; 1/250 years
  - Includes a Demand Rate Reduction Factor (DRRF) to account for factors in the process design that may assist in reducing the Demand Rate on a PRD
    - Fire Fighting Facilities
    - Process Control Layers of Protection (LOPA)

API RBI PRD Methodology

- Demand Rate
  - User selects applicable overpressure scenarios from choice list
  - Allows User to override demand rate

Overpressure Demand Case	Demand Rate	DRATE (events/year)	Reference
Fire	1 per 250 years	0.1	10.7
Blocked Discharge with Administrative Controls in Place	1 per 20	0.05	10.11
Blocked Discharge without Administrative Controls	1 per 10	0.1	10.11
Loss of Cooling Water Utility	1 per 12.5	0.08	10.7
Loss of Instrument Air	1 per 20	0.05	10.10
Thermal Relief with Administrative Controls in Place	1 per 20	0.05	Assumed same as Blocked Discharge
Thermal Relief without Administrative Controls	1 per 10	0.1	Assumed same as Blocked Discharge
Electrical Power Supply failure	1 per 12.5	0.08	10.7
Control Valve Failure	1 per 10	0.1	10.1
Tower P/A or Reflux Failures	1 per 12.5	0.08	Assumed same as electrical Power Failure
Runaway Chemical Reaction	1 per 50	0.02	10.7
Overfilling	1 per 15	0.067	
Hot Oil Contact with Water	1 per 15	0.067	
Heat Exchanger Tube Rupture	1 per 100	0.01	10.5

API RBI PRD Methodology

- Consequence of Failure
  - Discussed consequence methods already
  - Unlike fixed equipment RBI, the consequence modeler is run at much higher overpressures
    - Software calculates potential overpressure if the PRD fails to open on demand
    - Overpressure increases release amount and also increases probability of leaks and ruptures (GFFs are increased as a function of overpressure)
    - Some overpressure scenarios (fire, power failure) will result in rupture, if the PRD fails to open on demand
  - Accounts for PRD Criticality
    - Recognizes the fact that PRDs may have many different overpressure scenarios, some PRDs more critical than others
    - Enables the criticality of the PRD service to impact Risk, i.e. more critical services result in more risk
    - Links to protected equipment, PRDs protecting damaged equipment get more attention

API RBI PRD Methodology

- The calculation of risk for a PRD failing to open upon demand is calculated for EACH applicable demand case using the demand rate, the probability of failure of the PRD and the calculated overall consequence of failure for the demand case as follows:

$$Risk_{DC} = POF_{DC} \times COF_{DC}$$

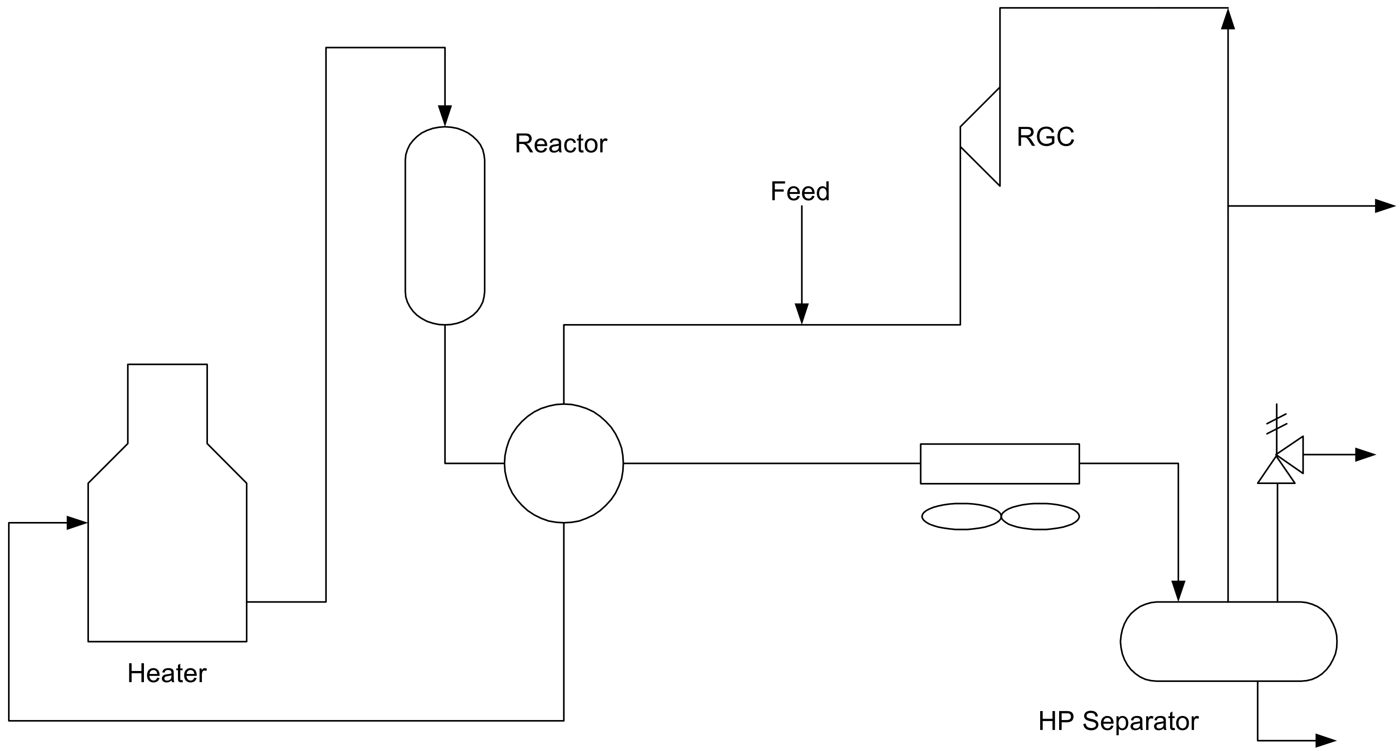
- The overall risk is then determined by adding up the individual risks associated with the applicable demand cases as follows:

$$Risk_{fto} = \sum_{i=1}^{n} POF_{DCi} \times COF_{DCi}$$

- where *i* represents each of the *n* number of applicable overpressure demand cases

API RBI PRD Methodology

- This is repeated for EACH piece of equipment or component protected by the PRD



PRV

PRD Tag	psv001	PRD Location	V-08101 SULFATREAT VESSEL
Analysis Type	RISK		

PRD Design Information | Overpressure Demand Cases | Consequence Analysis

General Data

Make / Model	Crosby Jos	Inlet Size (in)	3
Serial number		Outlet Size (in)	4
PID Number	DMF-1291	PRD Capacity (Lbs/Hour)	3000
PRD Area (in²)	3.6	Soft Seat	No
PRD Type	RDISC	Back Pressure (psig)	0
Operating Temperature (°F)	120.0000	Current Inspection Test Interval (yrs)	5
Install Date (yyyy-mm-dd)	2001-01-01	Min Allowed Inspection Interval (yrs)	1
Set Pressure (psig)	150	Max Allowed Inspection Interval (yrs)	10

Installation Details

Parallel Area (in²)	3.6	History Of Chatter	No
RD Upstream	No	History Of Actuation	Yes
Discharge Location	FLARE	Operates Close To Set	No
Pulsing Service	No	Installed Piping Vibration	No

Service Duty

Fluid	C3-C4
FTO Class	MILD
Leak Class	MILD

Weibull Parameters

FTO Alpha		FTO Beta	
Leak Alpha		Leak Beta	

Save | Help | Delete | Comments

PRV

PRD Tag: psv001
PRD Location: V-08101 | SULFATREAT VESSEL
Analysis Type: RISK

PRD Design Information | Overpressure Demand Cases | Consequence Analysis

Heat Exchanger Tube Rupture | User Specified Case 1 | User Specified Case 2 | Overall Demand Case
Liquid Overfill | Electrical Power Failure | TPA Or Reflux Pump Failure | Runaway Chemical Reaction
Fire | Blocked Discharge | Inlet Control Valve Failure | Outlet Control Valve Failure | Thermal Relief / Hydraulic Expansion | Loss Of Cooling

Demand Case Active	Yes
Event Frequency (events/year)	0
Demand Rate Reduction Factor	0
Upstream Pressure Source Type	Centrifugal Rotating Equip
Upstream Source Pressure (psig)	0
Deadhead Pressure (psig)	250
Number Of Block Valves	1
Block Valve Usage Frequency (yrs)	0
Heat Source Type	Other Internal or External Heat Source
Heat Source Temperature (°F)	400
Overpressure Potential (psig)	0
User Override Overpressure (psig)	0

Save | Help | Delete | Comments

Applied Filter: NONE

PRV

PRD Tag: psv001

PRD Location: V-08101 SULFATREAT VESSEL

Analysis Type: RISK

PRD Design Information | Overpressure Demand Cases | Consequence Analysis

PRD Specific Parameters

Leak Can Be Tolerated	Yes
Time To Discover Leak (days)	
Stuck Open Valve Tolerated	No
Environmental Cost ($)	
Fluid Cost ($/lb)	0
Cost To Repair PRV ($)	
Time To Repair PRV (days)	3

Unit Parameters

Equipment Cost ($/ft²)	1500.048
Production Cost ($/day)	50000.00
Injury Cost ($)	1.0000000E+07
Population Density (person/ft²)	1.0000323E-04
Unit Flare Recovery System	No
Unit Turnaround Frequency (yrs)	5
PRV Risk Tolerance ($)	30000

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Applied Filter: NONE

Protected Components

PRD Tag psv001

Available Components	Protected Components
E-08107-TS	08-0106-ARC-CS300-10 -GT
E-08108	08-0202-LSR-CS150-6 -GT
E-08108-TS	E-08109
E-08109-TS	V-08101
E-08110	V-08103
E-08110-TS	V-08111
E-08111A	
E-08111A-TS	
E-08111B	
E-08111B-TS	
E-08111C	
E-08111C-TS	
E-08111D	
E-08111D-TS	
E-08111E	
E-08111E-TS	
E-08111F	
E-08111F-TS	
E-08112	
E-08112-TS	
E-08113	
E-08113-TS	
E-08114	
E-08114-TS	
E-08116A	
E-08116A-TS	
E-08116B	
E-08116B-TS	

PRV Location V-08101

Save Help

Applied Filter: NONE

0.1.1.50 (PRV)
a
b
c
CRUDE UNIT 3
psv001

PRV Results

Analysis Type RISK

PRV Location V-08101 SULFATREAT VESSEL

PRV Details

#	Component	Fluid_Name	DRisk_FTO ($)	DRisk_Leak ($)	DRisk_Total...	Testint_Calculated
1	E-08109	C13-C16	3750.327	14970.38	18720.70	5.000000
2	08-0106-ARC-CS300	Water	8.8559999E-04	1695.774	1695.775	5.000000
3	08-0202-LSR-CS150-	C5	92624.03	588.8787	93212.91	5.000000
4	V-08101	C3-C4	295343.6	494.9572	295838.5	5.000000
5	V-08103	C3-C4	295202.9	598.0364	295801.0	5.000000
6	V-08111	C5	306895.8	588.8787	307484.7	5.000000

OK

4

Save Help Delete Details

Applied Filter: NONE

API RBI PRD Module

- Direct Link to Fixed Equipment
  - New PRD Protection Database Table which links PRDs to their protected equipment
    - Handles equipment protected by multiple PRDs
    - Handles multiple pieces of equipment protected by common PRD(s)
  - Significantly reduces amount of input for PRDs. Links PRD to inventory group, operating and design conditions, fluid properties and most importantly to the damage state of the protected equipment
  - PRD RBI cannot currently be performed without fixed equipment RBI

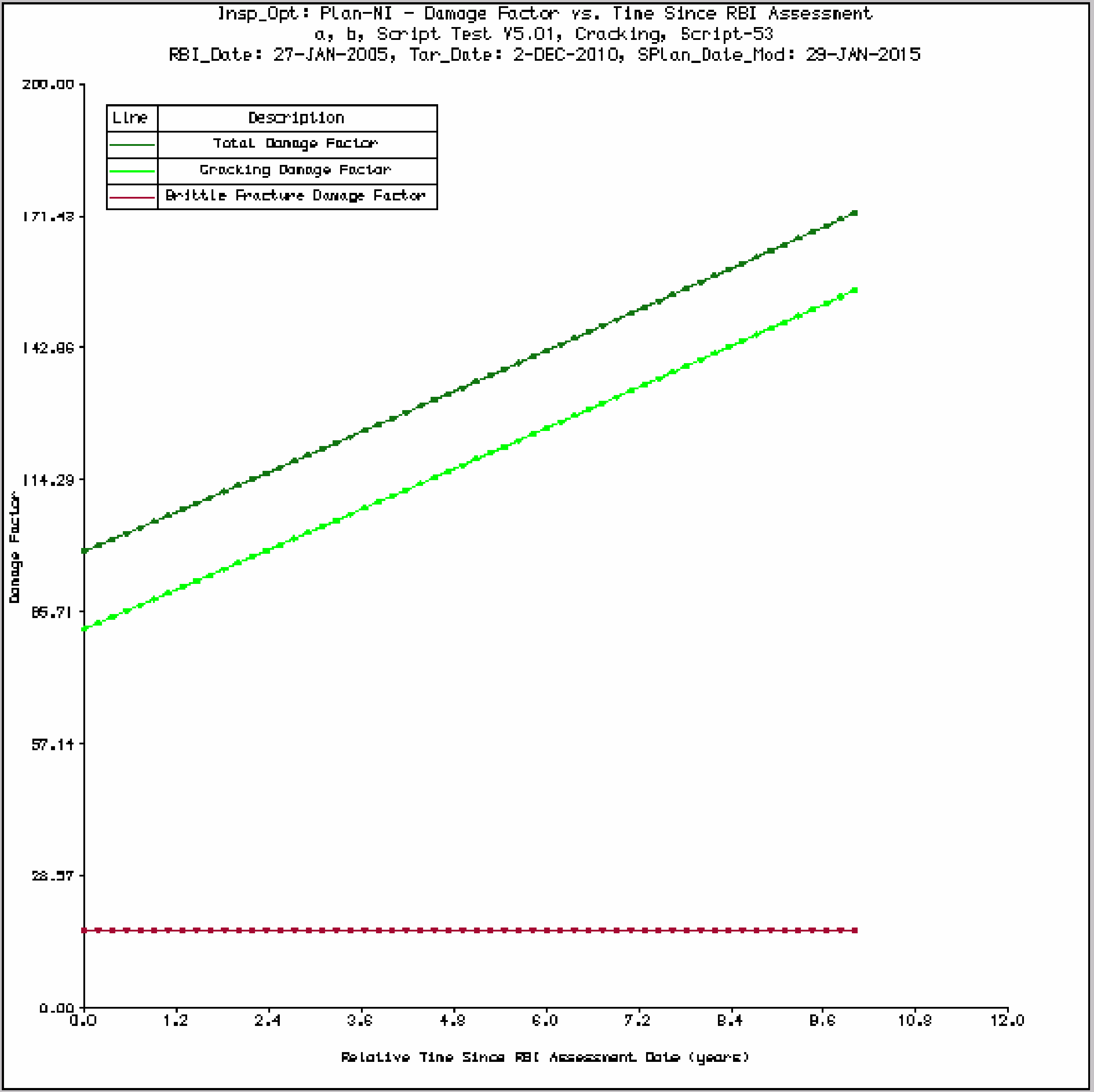
API RBI PRD Module

- Direct Link to Fixed Equipment
  - Recognizes the fact that damaged vessels are at higher risk to failed PRD than undamaged vessels, current PRD module does not consider the protected equipment damage state.
  - Also, since damage factor of the protected equipment increases as a function of time so does the risk associated with the PRD protecting it
  - Allows risk ranking of PRDs versus fixed equipment

Available Plots

- Risk
- Risk Pie
- Risk Bar
- Risk No Inspection
- Risk Pie No Inspection
- Risk Bar No Inspection
- DF
- DF No Inspection

Ok



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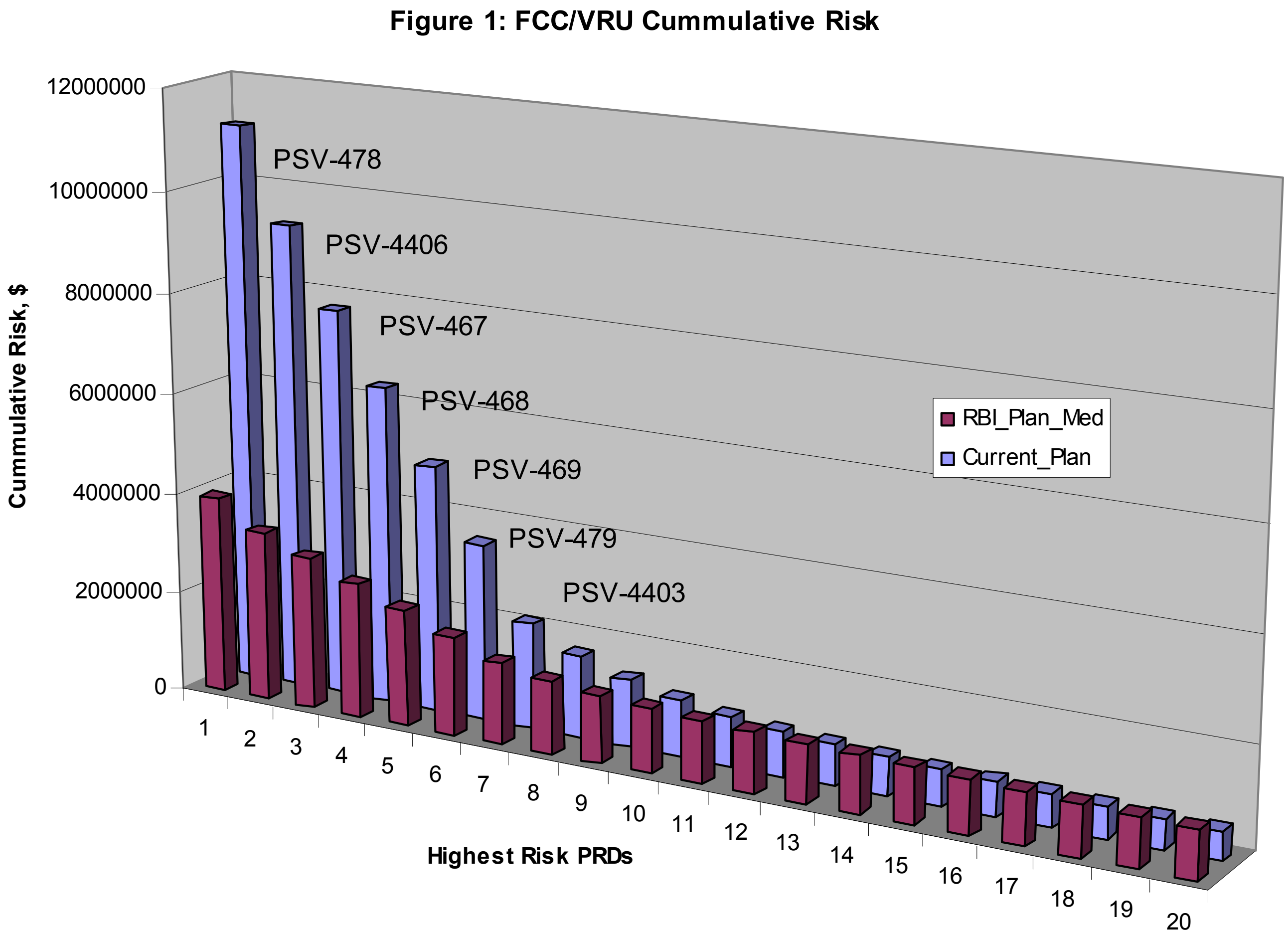
API RBI PRD Module

- Case Studies
  - FCC Unit
    - 84 PRDs
    - Intervals set according to API 510, typically set at 5 years (60 months)
    - 95% of Risk was related to 17 PRDs, those protecting the major towers in the unit
    - Reduced interval on 14 PRDs, 3 remained unchanged, increased intervals on 67 PRDs
    - Average interval increased from 69 to 97 months
    - Risk reduction of 65%, minor increase in inspection costs

API RBI PRD Module

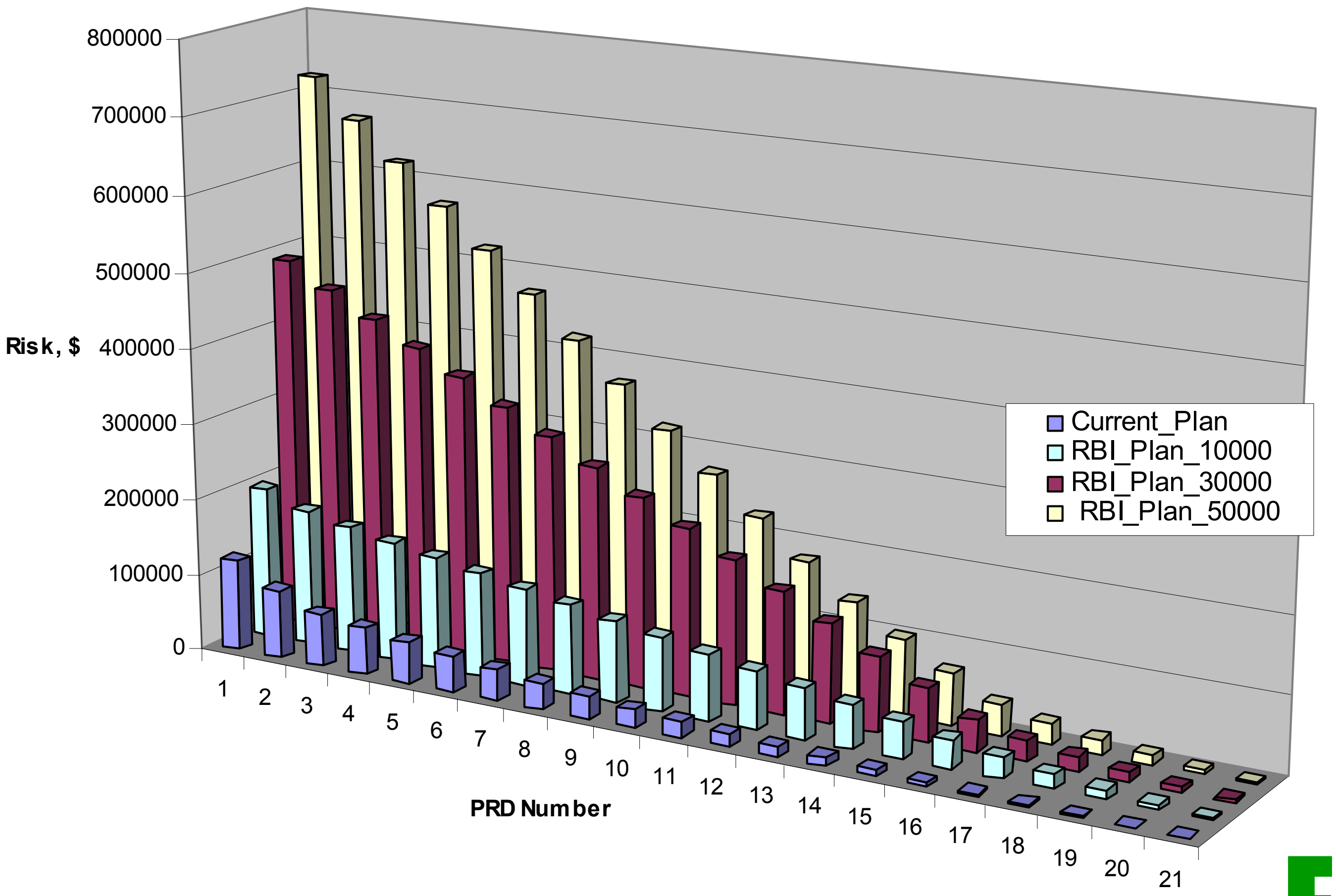


API RBI PRD Module

- Case Studies (Con't.)
  - COGEN Unit
    - 21 PRDs
    - Natural Gas, Steam, Carbon Monoxide
    - Intervals set at 18 months, VERY conservative
    - Client unsure of risk tolerance, ran sensitivity analysis (RT = $10K, $30K and $50K)
    - RBI plan increased average interval to 86 months
    - 80% reduction in inspection costs
    - Significant increase in risk, based on Clients risk tolerance

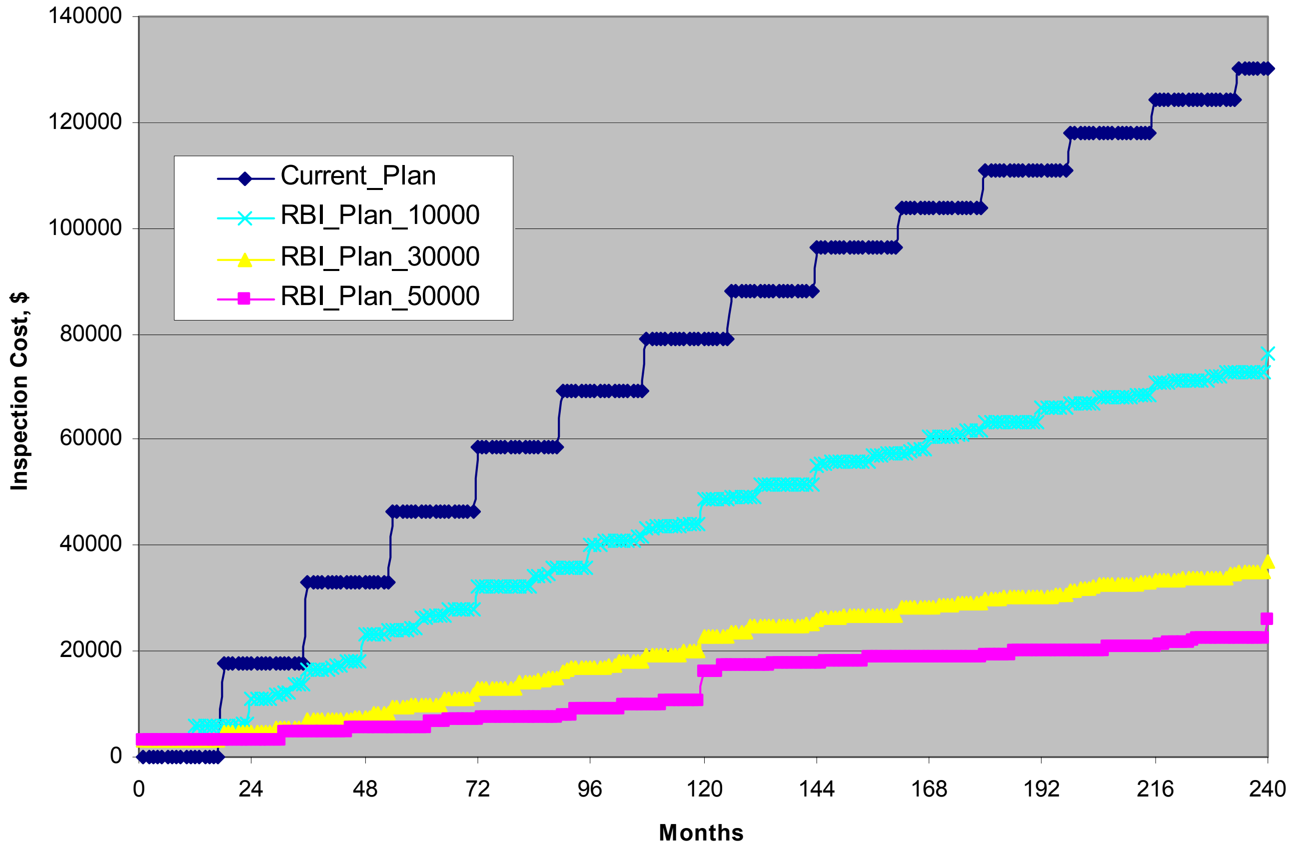
API RBI PRD Module

Figure 1: Geismar Cogen Unit Cummulative Risk



API RBI PRD Module

Figure 2: Net Present Value of Inspection Costs

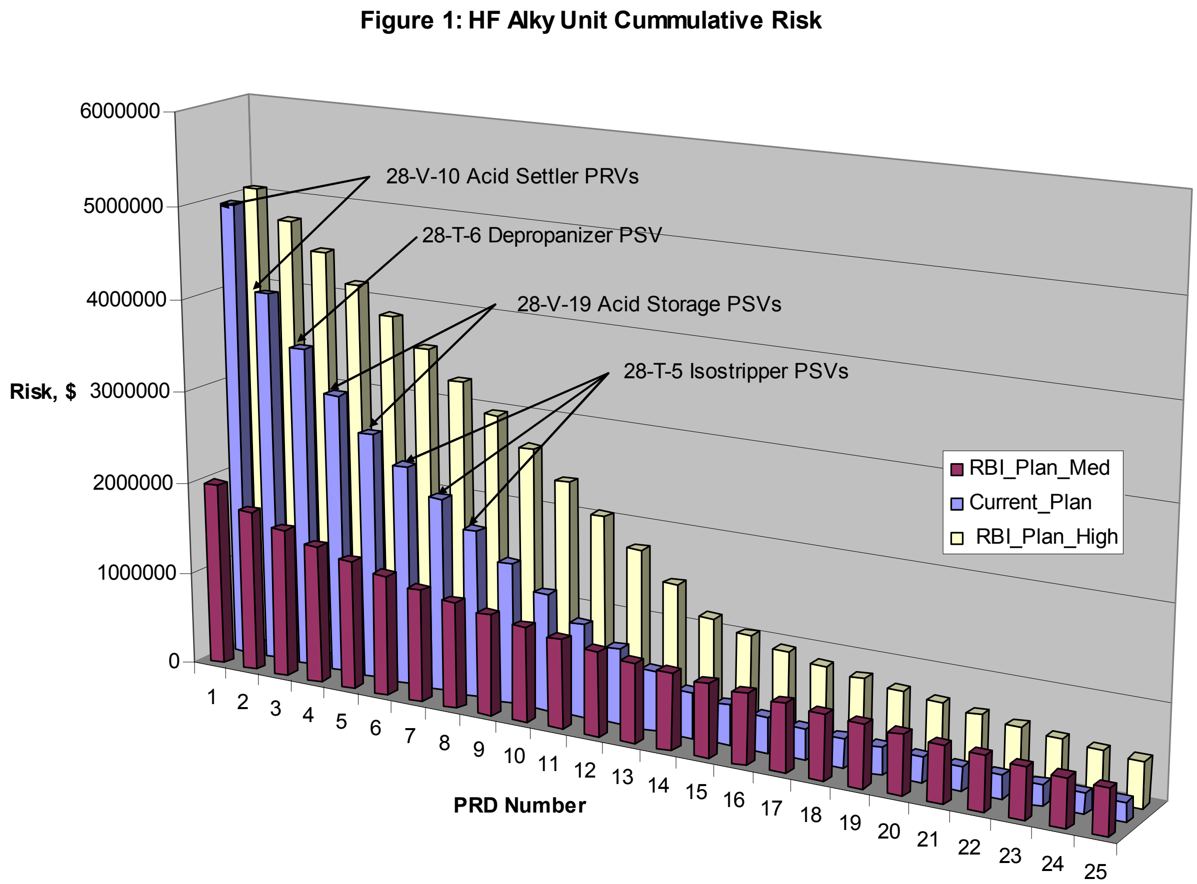


E2G

API RBI PRD Module

- Case Studies (Con't.)
  - HF Unit
    - 129 PRDs
    - Intervals set in accordance with API 510, typically 60 months
    - Average interval increased from 59 months to 106 months using an RBI plan
    - Reduced intervals on critical PRDs protecting towers and HF storage
    - Reduced interval on 14 PRDs, 1 remained unchanged, increased intervals on 74 PRDs
    - 18% reduction in inspection costs
    - 60% reduction in risk

API RBI PRD Module



API RBI PRD Module

- Case Studies (Con't.)
  - Hydrotreater Unit
    - 23 PRDs
    - Intervals set at 60 months
    - 95% of the risk from 5 PRDs (20%)
    - Average interval increased to 94 months
    - Reduced interval on 5 PRDs, 1 remained unchanged, increased intervals on 17 PRDs
    - significant reduction in inspection costs
    - 80% reduction in risk
    - Much better job optimizing inspection costs than VCERelief, which recommended 57 month average interval with not near the risk reduction

API RBI PRD Module