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A step change in traditional Risk Assessment Techniques for Process Safety and Asset Integrity Management

Annamaria Petrone
enì e&p

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl
1. Process Safety and Asset Integrity: definitions
2. Process Safety Management during asset lifecycle
3. Occupational Safety vs. Process Safety
4. The Barrier Concept
5. Risk Analysis tools for Process Safety
6. B.A.R.T. BAseline Risk Assessment Tool
7. Conclusions
Process Safety and Asset Integrity: Definition

**Asset Performance**
Asset ability to perform its function while maximizing business

**Asset Integrity**
Ability of asset to perform its function while safeguarding life and environment

**Process Safety**
Management of major accidents with energy release

**Occupational Safety**
Management of incidents affecting individuals
Process Safety Management during asset life cycle

- Emergency preparedness
- Planning and resourcing
- Operations/maintenance
- Change management
- Commissioning and start up
- Risk management
- Technical Standards
- Integrity/Quality assurance

Key Interactions:
- Asset Integrity
- Design Integrity
- Technical Integrity
- Operating Integrity
- Process Integrity

Life Cycle Stages:
- Design
- Emergency preparedness
- Planning and resourcing
- Operations/maintenance
- Change management
- Commissioning and start up
Occupational Safety vs. Process Safety

Occupational Hazard

- Single Injuries / Fatalities
- Recurrent Root Causes:
  - Poor supervision
  - Human error
  - Lack of attention

Process Safety Hazard

- Multiple Injuries / Fatalities
- Recurrent Root Causes:
  - Malfunctions
  - Human error
  - Deviation from operating procedures
Occupational Safety Risks

Related to the violation of Golden Safety Rules

- **Safe Driving** → Safety Belts, Speed Limits, Defensive Driving etc.
- **Track the Changes** → Changes reported & understood By-Pass approved
- **Operating Lifting Safely** → Operators trained Lifting device certified
- **Prevent Fires** → Firefighting Equipment, Fire Team in place, ER plan
- **Mind the Height** → Scaffolding properly erected, Fall Arrestor Devices,
- **Isolate Energized Systems** → Qualified de-energizer /team Work Permits
- **Stabilize excavations** → Work Permit Proper Slope Benches,
- **Handle Permits to Work (PTW)** → PTW System in place and understood
- **Apply Healthcare Solutions** → Safety Data Sheets, Medical Certificates
- **Protect Your self** → Head, eyes, hand, feet, and ears protection
Occupational Safety vs. Process Safety

An operator walks through a process unit and slips and falls to the ground and suffers a days away from work injury.

The slip/fall is due to weather conditions, “chronic” oily floors and slippery shoes.

A maintenance contractor opens a process valve and gets sprayed and this results in a severe burn and days away from work.

This is an Occupational Safety Accident

This is a Process Safety Accident
Occupational Safety vs. Process Safety

Major Accident Hazard
(multiple fatalities)

Slips, Trips, Falls
(single fatality)

CONSEQUENCES

Process Safety

Occupational Safety

Very unlikely

Possible

LIKELIHOOD

Equivalent Risk
In order to prevent or mitigate a hazard, **Barriers** are required.

**CONSEQUENCES**

- Major Accident Hazard (multiple fatalities)
- Slips, Trips, Falls (single fatality)

**LIKELIHOOD**

- Very unlikely
- Possible

**Process Safety**

**Prevention**

**Occupational Safety**

**Mitigation**

**Equivalent Risk**
The Barrier Concept

A **Barrier** is a functional grouping of safeguards and controls selected to prevent the realization of a hazard.

**Swiss Cheese Model**

Incidents occur when one or more holes in each of the slices become aligned, allowing for ‘a trajectory’ of accident opportunity.
The Barrier Concept – Occupational Hazard

HAZARD

Operating procedures

Training

Inspection and maintenance

Fall Protection Systems

HARM

Single fatality

WORKING AT HEIGHT

FALLING FROM HEIGHT
The Barrier concept – Process Safety Hazard

HAZARD

HYDROCARBON UNDER PRESSURE

Process Control System

Maintenance Program

Operating Procedures

Inspection and monitoring

HARM

Multiple fatalities

HYDROCARBON RELEASE FIRE-EXPLOSION
Risk Analysis Tools for Process Safety

Early Design Phases
- Experience and Judgment
- Checklists Analysis
- Codes and Standards
- Preliminary Process Screenings
- Preliminary Hazard Identification

Later Design Phases
- RBI
- FMECA
- RAM
- Root Cause Analysis
- What-if Analysis
- HAZOP
- Quantitative Risk Analysis
Risk Analysis Tools for Process Safety

FAULT TREE (Causes)
- Threat 1
- Threat 2
- Threat 3

PREVENTIVE BARRIERS

EVENT TREE (Consequences)
- Consequence 1
- Consequence 2
- Consequence 3

RECOVERY BARRIERS

HAZARD SOURCE

ESCALATION

Hazardous event
e.g. Loss of Containment
Risk Analysis Tools for Process Safety

- **Bow tie**: good way to establish relationships between Hazard, Top Events, Threats and Consequences

- **Preventive Safeguards** reduce the likelihood of occurrence of the loss event (e.g. primary containment systems)

- **Recovery safeguards** reduce the severity of consequences (e.g. detectors)
Risk Analysis Tools for Process safety

**Qualitative Risk Analysis**

- Structured approach for Qualitative evaluation of Frequency and severity

### Consequence

<table>
<thead>
<tr>
<th>Severity</th>
<th>People</th>
<th>Environment</th>
<th>Assets</th>
<th>Reputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slight injury</td>
<td>Slight effect</td>
<td>Slight damage</td>
<td>Slight impact</td>
</tr>
<tr>
<td>2</td>
<td>Minor injury</td>
<td>Minor effect</td>
<td>Minor damage</td>
<td>Minor impact</td>
</tr>
<tr>
<td>3</td>
<td>Major injury</td>
<td>Local effect</td>
<td>Local damage</td>
<td>Local impact</td>
</tr>
<tr>
<td>4</td>
<td>One fatality</td>
<td>Major effect</td>
<td>Major damage</td>
<td>Major impact</td>
</tr>
<tr>
<td>5</td>
<td>Multiple fatalities</td>
<td>Extensive effect</td>
<td>Extensive damage</td>
<td>Extensive impact</td>
</tr>
</tbody>
</table>

### Increasing Annual Frequency

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Non-credible</td>
<td>Rare</td>
<td>Unlikely</td>
<td>Credible</td>
<td>Probable</td>
<td>Frequent</td>
</tr>
<tr>
<td>Consequence</td>
<td>Could happen in E&amp;P industry</td>
<td>Heard in E&amp;P industry</td>
<td>Has occurred at once in Company</td>
<td>Has occurred several times in Company</td>
<td>Happens several times/y in Company</td>
<td>Happen several times/y in one location</td>
</tr>
</tbody>
</table>

### Risk Reduction Measures

- **Continuous Improvement**
- **Risk Reduction Measures**
- **Intolerable Risk**

---

1. Slight injury
2. Minor injury
3. Major injury
4. One fatality
5. Multiple fatalities
Risk Analysis Tools for Process safety

Quantitative Risk Analysis (QRA)

- Structured approach to Quantify Frequency and Severity
- Powerful tool during design phase and for ALARP demonstration
Risk Analysis Tools for Process Safety

QRA methodology limitations

- **some hardware barriers** (e.g. the ESD) not considered
- **contribution of operational barriers** not quantifiable
- need of clear definition of working **time spent by operators**
- easily **misused** to justify deviation from standards
- **Uncertainties in input** resulting in unrealistic outputs
Combination of a simplified QRA with a Bow-Tie Method

- **Simplified QRA:**
  to estimate the Initial Risk level of each functional unit, assuming no barriers in place.

- **Bow-Tie Methodology:**
  assess the Risk level taking into account the safety barriers and their effectiveness in prevention and mitigation.

```
B.A.R.T.  BAseline Risk Assessment Tool
```

```
Combination of a simplified QRA with a Bow-Tie Method
```

```
Hazard
  └── Consequence
    └── Vulnerability
      └── Frequency
```

```
Initial Risk
```

```
Classification Criteria
```

```
Threat
 ┴── DEVIATION
  └── Loss event
```

```
HA Z A R D
```

```
CO N S E Q U E N C E
```

```
20
```
B.A.R.T. BAseline Risk Assessment Tool

- BART project started in 2008; first trial on site in 2009
- Result of the cooperation between eni e&p safety department and eni engineering company (Tecnomare)
- Subjected to a Critical review by DNV
- Successfully applied so far to over twenty installations
- Presented at international conferences\(^1\) workshops\(^2\) and on technical journals\(^3\)

---

1. SPE 146845 - ATCE 2011, IPTC 2011; SPE 156521- APPEA 2012; AIChE 6\(^{th}\) Global Congress on Process Safety),
2. 5\(^{th}\) Annual HSE Excellence Europe – London; Asset Integrity Workshop Stavanger
3. AIChE Process Safety Progress- Volume 30
BART is a Risk Assessment Methodology to:

- identify and analyze all potential process safety hazards that can lead to major incidents
- determine the current level of process safety risk and define controls aimed at reducing it ALARP
- Establish effective Risk Reduction measure and support Management in the Decision Making Process

The methodology applies to both onshore and offshore installations

(ALARP: As Low As Reasonably Practicable)
B.A.R.T. BAaseline Risk Assessment Tool

- BART methodology is consistent with the Risk Management process outlined in the OGP Asset integrity Report:
B.A.R.T. BAaseline Risk Assessment Tool

1st step: Plant Modelling

Plant Layout:
- Functional Units
- Safety Distances

Process Characteristics:
- Equipment List per Unit
- Fluid Properties
- Operating Conditions

Safety Distances:
- Unit Length and Width
- Minimum dimension of the functional unit
- Minimum distance from other plant units and permanently manned areas
2nd Step: Initial Risk

Determine the initial release frequency and estimate consequences with a simplified QRA. The major incident scenarios considered are:

- Jet Fire
- Pool Fire
- Flash Fire
- Explosion
- Toxic Release

Release Frequency evaluation

Consequence modelling
Scenario frequencies and consequences are recombined, assessed and displayed in a **Risk Screening Matrix**

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Increasing Annual Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Severity</strong></td>
<td><strong>People</strong></td>
</tr>
<tr>
<td>1</td>
<td>Slight health effect</td>
</tr>
<tr>
<td>2</td>
<td>Minor health effect</td>
</tr>
<tr>
<td>3</td>
<td>Major health effect</td>
</tr>
<tr>
<td>4</td>
<td>One fatality</td>
</tr>
<tr>
<td>5</td>
<td>Multiple fatalities</td>
</tr>
</tbody>
</table>

**Consequence**
- 1: Slight health effect
- 2: Minor health effect
- 3: Major health effect
- 4: One fatality
- 5: Multiple fatalities

**Increasing Annual Frequency**
- 0: Non-credible
- A: Rare
- B: Unlikely
- C: Credible
- D: Probable
- E: Frequent

- Could happen in E&P industry
- Heard in E&P industry
- Has occurred at once in Company
- Has occurred several times in Company
- Happens several times/y in Company
- Happen several times/y in one location

**Risk Screening Matrix**

- **Continuous Improvement**
- **Risk Reduction**
- **Intolerable Risk**

**INITIAL RISK**
3rd Step: Current Risk

- Identify and select the controls forming an “independent barrier”.

- Evaluate the reliability of the barriers in place with dedicated checklists and interviews on site.

- Assess current risk for each unit.
  - Reduce likelihood of initial Risk with Preventive Barriers
  - Reduce consequences of initial Risk with Recovery Barriers.
What causes the hazard to be released?
How can control be lost?

- Human error (own staff + contractors)
- Equipment failure
- Deviation from design operating practices
Identification of Preventive Safeguards

- How do we prevent the hazard from being released?
- How do we keep control?

- Human error (own staff + contractors)
- Competent Staff
- Operating Procedures
- Training
- Equipment failure
- Design Functional Requirements
- Maintenance Program
- Inspection / Monitoring program
- Deviation from design operating practices
- Process Control System
- Pressure Control System
- Gas Detection System
- Emergency Shutdown System
- Emergency Blowdown System
- Flaring / Venting System
B.A.R.T. BAaseline Risk Assessment Tool

Identification of Recovery Safeguards

- How do we limit the severity of the event?
- How do we minimise the effects?

[JET FIRE]

- Fire Detection System
- Emergency Shutdown System
- Emergency Blowdown System
- Flaring / Venting System

Fixed Fire-fighting Equipment → Fire-fighting Team → Passive fire Protection System → Damage to Property

Emergency Response Plan → Emergency Response Team → Emergency Evacuation and Rescue Equipment → Harm to People
How might controls fail? How do we make sure they don’t?
How could their effectiveness be undermined?
<table>
<thead>
<tr>
<th>Barrier Name</th>
<th>Reliability</th>
<th>Basic Controls</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Functionality</td>
<td>MEDIUM</td>
<td>Equipment Integrity</td>
<td>MEDIUM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inspection and testing</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintenance Management system</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Task Management</td>
<td>LOW</td>
<td>Staff competence training and awareness</td>
<td>LOW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contract HSE Requirements</td>
<td>LOW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Process Safety Rules for Operations</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Management of changes</td>
<td>LOW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operating Procedures</td>
<td>LOW</td>
</tr>
<tr>
<td>Process Safety Management System</td>
<td>MEDIUM</td>
<td>Process Safety Leadership &amp; commitment</td>
<td>MEDIUM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Process Safety Culture</td>
<td>MEDIUM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Process Safety Audit</td>
<td>LOW</td>
</tr>
</tbody>
</table>

Barrier Reliability - Preventive Barriers
<table>
<thead>
<tr>
<th>Barrier Name</th>
<th>Reliability</th>
<th>Basic Controls</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Management</td>
<td>MEDIUM</td>
<td>Fire-fighting Team</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fixed fire-fighting systems</td>
<td>MEDIUM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mobile and portable fire fighting system</td>
<td>HIGH</td>
</tr>
<tr>
<td>Plant Layout</td>
<td>MEDIUM</td>
<td>Plant Layout</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Emergency Response System</td>
<td>MEDIUM</td>
<td>Contingency and Emergency Response Plan</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication Systems</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emergency Response Team</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emergency Power Supply System</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Escape evacuation and Rescue Equipment</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Temporary Refuge</td>
<td>LOW</td>
<td>Temporary Refuge</td>
<td>LOW</td>
</tr>
</tbody>
</table>
## B.A.R.T. BAaseline Risk Assessment Tool (11/16)

### BART Checklist

<table>
<thead>
<tr>
<th>ID</th>
<th>EMERGENCY RESPONSE TEAM</th>
<th>Score</th>
<th>Y/N</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Are emergency response team trained on contingency and emergency response and evacuation procedures?</td>
<td>2</td>
<td>Y</td>
<td>ER training has been provided</td>
</tr>
<tr>
<td>2</td>
<td>Are emergency response team fully aware of their roles and responsibilities on emergency?</td>
<td>1</td>
<td>N</td>
<td>ER roles &amp; responsibilities are included in training</td>
</tr>
<tr>
<td>3</td>
<td>Are emergency response team properly equipped and trained on the use of emergency devices and tools?</td>
<td>2</td>
<td>Y</td>
<td>The fire/rescue contractor has trained and experienced staff.</td>
</tr>
<tr>
<td>4</td>
<td>Is available a documented training programme for the emergency response team members and training records are kept?</td>
<td>2</td>
<td>Y</td>
<td>The fire/rescue contractor has records of all training to staff conducted</td>
</tr>
</tbody>
</table>

**TOTAL**: 7 6 86%
Once known number and reliability of all barriers in place, the initial risk frequency can be decreased:

- Each HIGH-reliability preventive / recovery barrier reduces the initial frequency / consequence by one order of magnitude.
- LOW - or MEDIUM-reliability barriers if combined can act as HIGH-reliability barriers.
B.A.R.T. BAseline Risk Assessment Tool

LOSS OF INTEGRITY/CONTROL

- Human Error
- Equip Failure
- Dev. Operat. cond.

Task Manag.
Process Safety MS

Design Integrity
Operat. Integrity

Process Control System
Pressure Protection System

Toxic Gas Release
- Toxic Leak Cont. System
- Toxic Isol. and depr. System

CS
B3

PEOPLE
<table>
<thead>
<tr>
<th>Unit</th>
<th>Event</th>
<th>Current Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Human Error</td>
</tr>
<tr>
<td>AGP Heaters</td>
<td>FF</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>A5</td>
</tr>
<tr>
<td>Compression</td>
<td>EX</td>
<td>B4</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>C4</td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>C5</td>
</tr>
<tr>
<td>Dehydration</td>
<td>FF</td>
<td>B4</td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>B5</td>
</tr>
<tr>
<td>Emulsion Heaters</td>
<td>FF</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>B3</td>
</tr>
<tr>
<td>Inlet Separators</td>
<td>FF</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>A4</td>
</tr>
<tr>
<td>LP Separators</td>
<td>FF</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>A4</td>
</tr>
</tbody>
</table>
**4th step: Future Risk**

**Recommended Actions:**

- identified for each preventive and recovery control, whose poor reliability affect the whole barrier effectiveness
- aimed at improving the reliability of existing barriers

**Future Risk Reduction Scenarios**

- Simulation of different “scenarios” to reduce overall risk implementing one or more recommended actions
- facilitates the decision process in selecting the most appropriate risk-reduction strategy.
## B.A.R.T. BAseline Risk Assessment Tool

### Recommended Actions

<table>
<thead>
<tr>
<th>CASE</th>
<th>RISK REDUCTION SCENARIO</th>
<th>CONTROLS</th>
<th>HIGH Risk Reduction</th>
</tr>
</thead>
</table>
| 1    | Prevention of Equipment Failure                    | • Maintenance Management
• Inspection & Testing
• Equipment Integrity
…               | - 33%                                           | - 33%               |
| 2    | Revamping of Isolation & Depressurization System   | • Gas Detection System
• Fire Detection System
• Emergency Blowdown
…               | - 50%                                           | - 78%               |
| 3    | Mitigation of Fire Scenarios                      | • Fixed Fire-fighting System
• Mobile/portable fire-fighting
• Spill containment System
…               | - 38%                                           | - 67%               |

Simulation of risk reduction scenarios
## Significant Risk Scenarios – Future Risks

<table>
<thead>
<tr>
<th>Unit</th>
<th>Event</th>
<th>Future Risk</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Human Error</td>
<td>Equipment Failure</td>
<td>Deviation Process</td>
<td></td>
</tr>
<tr>
<td>AGP Heaters</td>
<td>FF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td>Compression</td>
<td>EX</td>
<td>A4</td>
<td>A4</td>
<td>A4</td>
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<td></td>
<td>FF</td>
<td>B4</td>
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<tr>
<td></td>
<td>JF</td>
<td>B3</td>
<td>B3</td>
<td>C3</td>
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</tr>
<tr>
<td>Dehydration</td>
<td>FF</td>
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<td>A4</td>
<td>A4</td>
<td>B4</td>
<td></td>
</tr>
<tr>
<td>Emulsion Heaters</td>
<td>FF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>A3</td>
<td>A3</td>
<td>B3</td>
<td></td>
</tr>
<tr>
<td>Inlet Separators</td>
<td>FF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
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<td></td>
<td>PF</td>
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<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td>LP Separators</td>
<td>FF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>04</td>
<td>04</td>
<td>A4</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- **Process Safety** and **Occupational Safety** as key drivers in E&P Operations

- **Effective barriers** needed to prevent major hazards

- Need for **innovation** in traditional risk assessment methodologies
Conclusions

- **B.A.R.T** proposed as a **step change** for **Process Safety** Risk Assessment

- **Methodology and dedicated software** based on the combination of QRA and Bow Tie

- It offers **Risk Reduction Strategies** to assist the management in the **decision making process**.
THANK YOU FOR YOUR KIND ATTENTION!
Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation

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