Developing Safety Requirements and Designing Safe Products

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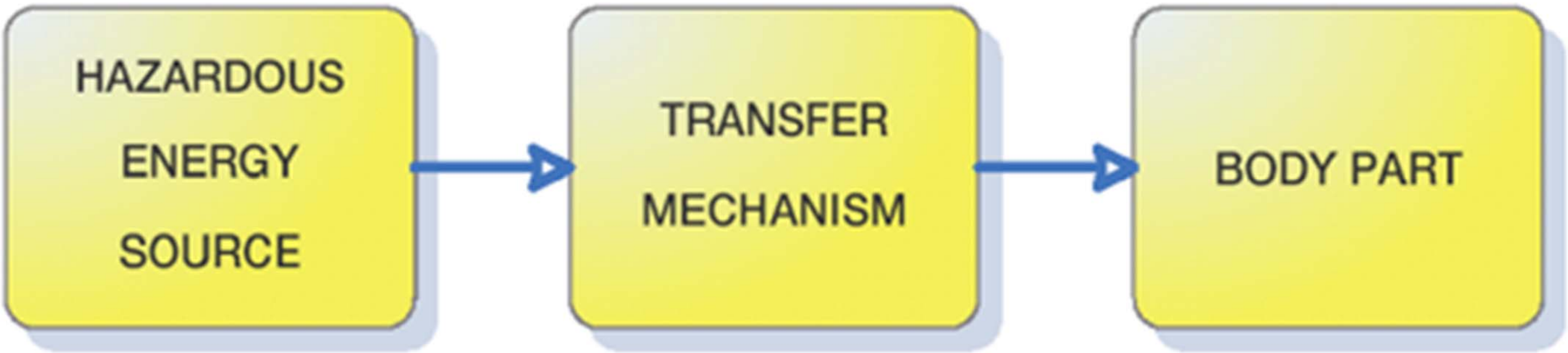
INTRODUCTION

This presentation will cover:

- Hazard-Based Safety Engineering (HBSE)
- Safeguards
- Fault Trees
- Examples
- Failure Modes and Effects Analysis
- Classification of Power Sources
- ASSET™
- Final Exam
- Questions

Hazard-Based Safety Engineering (HBSE)

HBSE – 3-Block Energy Transfer Model



HBSE – Energy Transfer

Within the **Three-block Energy Transfer Model,** there are two Models for NO Injury:

- the Non-hazardous Energy Source Model
- the Energy Attenuator Model

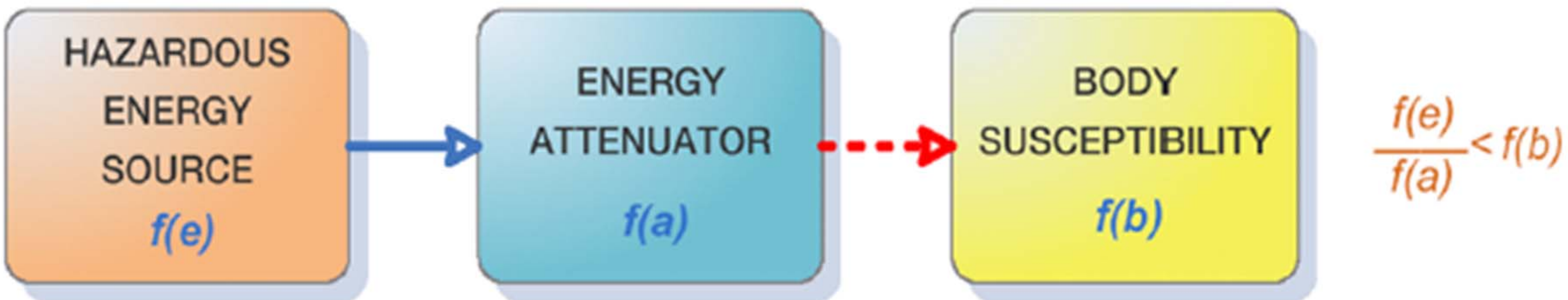
HBSE – Non-hazardous Energy Source Model

HBSE – Non-hazardous Energy Source Model

Examples:

- Safety extra low voltage circuit (SELV)
- Limited current circuit
- Pot of cool water
- Class I laser

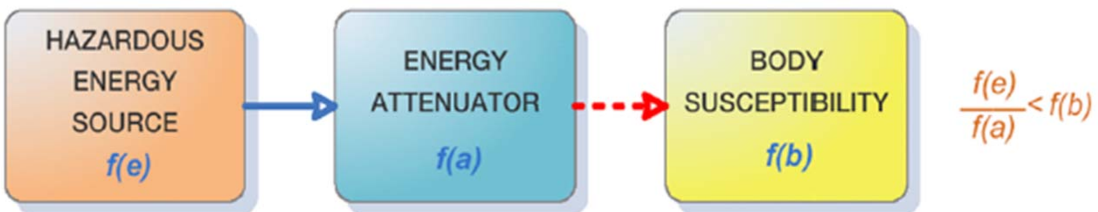
HBSE – Energy Attenuator Model



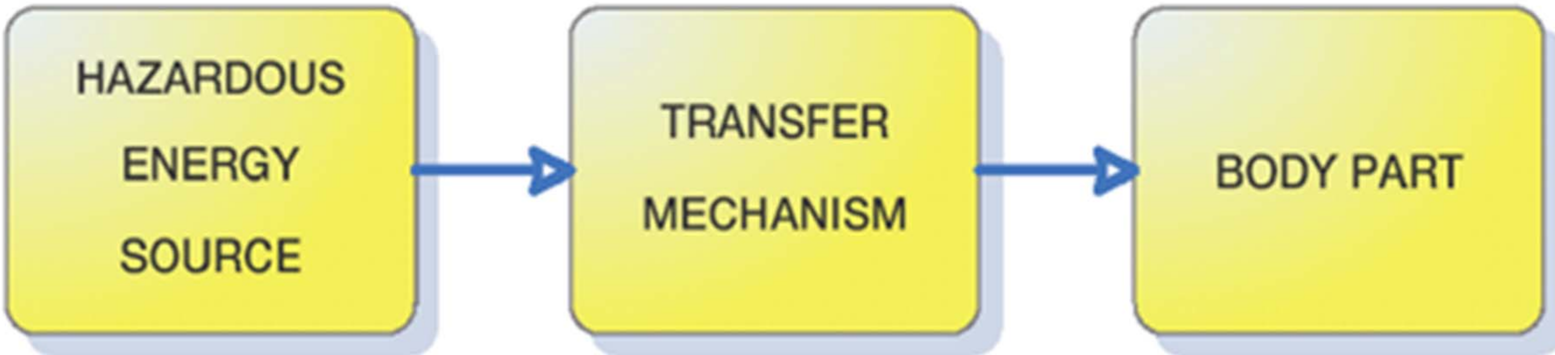
HBSE – Energy Attenuator Model

Examples:

- Electrical insulation
- GFCI
- Grounding
- SPDs
- Pot holder
- Sun screen



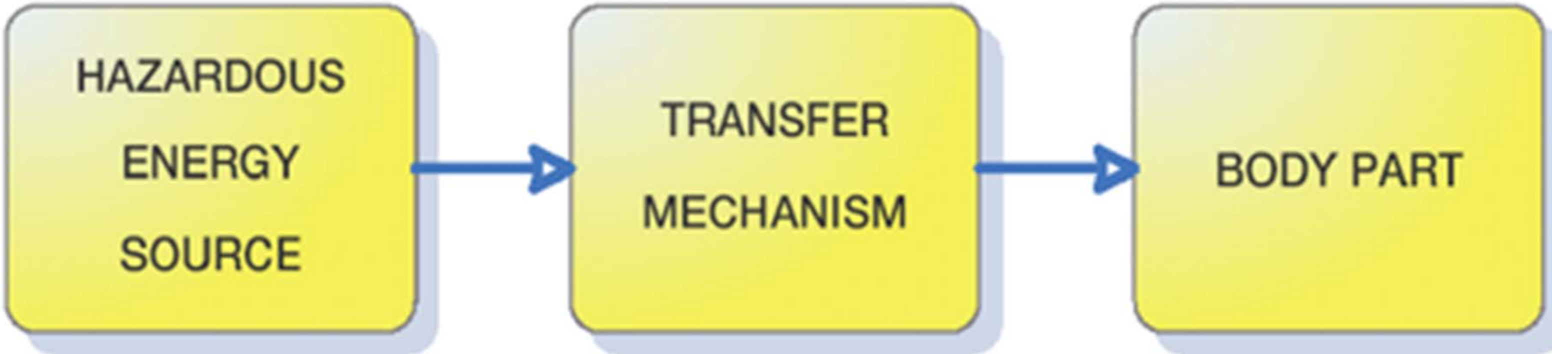
HBSE – 3-Block Energy Transfer Model



In most cases, the Transfer Mechanism determines whether an injury occurs.

HBSE – 3-Block Model for Safety

HBSE – 3-Block Energy Transfer Model



DEMONSTRATION

HBSE

(1), “Identify Energy Source”

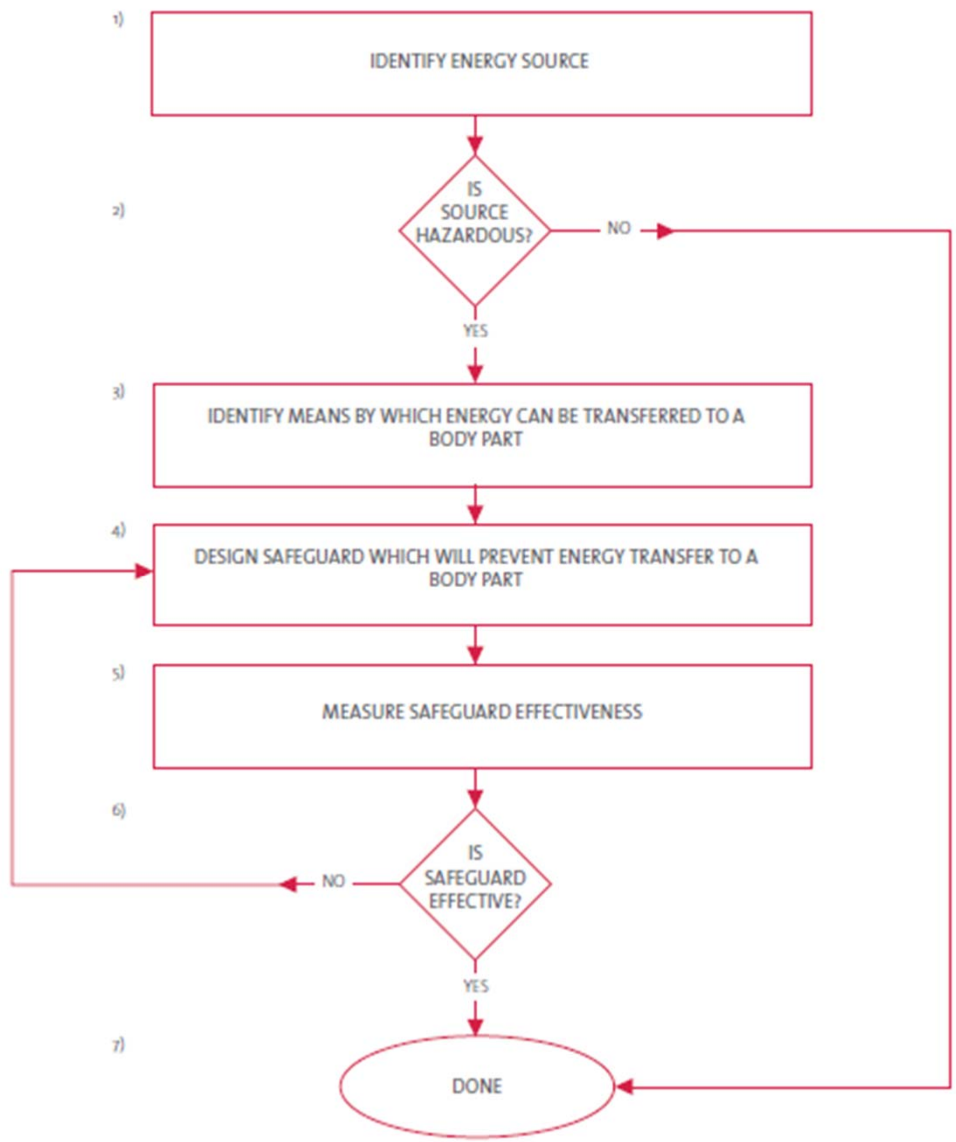
(2), “Is Source Hazardous”

(3), “Identify Transfer Means

(4), “Design Safeguard Which Will Prevent Energy Transfer to a Body Part”

(5), “Measure Safeguard Effectiveness”

(6) “Is Safeguard Effective”



Safeguards

HBSE – 3-Block Model for Safety

HBSE - SAFEGUARDS

A safeguard provides one or more of the following:

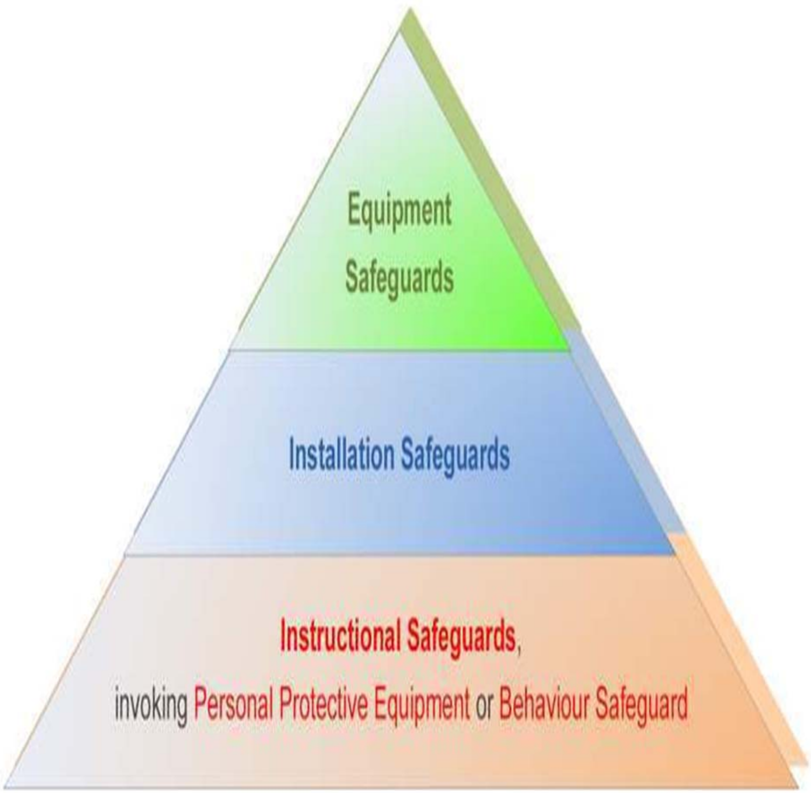
- Attenuates the energy
- Impede the energy (slows rate of transfer)
- Divert the energy (change its direction)
- Disconnect or disable the energy source
- Envelope the energy source (keep it from escaping)
- Interposing a barrier between a body part and the energy source

HBSE - SAFEGUARDS

Equipment Safeguard

Installation Safeguard

Instructional Safeguard



HBSE - SAFEGUARDS

Equipment Safeguard

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Instructional Safeguard

HBSE - SAFEGUARDS

Equipment Safeguard

Installation Safeguard

+

Instructional Safeguard

HBSE - SAFEGUARDS

DURESS

- **D**urability
- **U**sability
- **R**eliability
- **E**fficacy
- **S**uitability
- **S**calability

HBSE - SAFEGUARDS

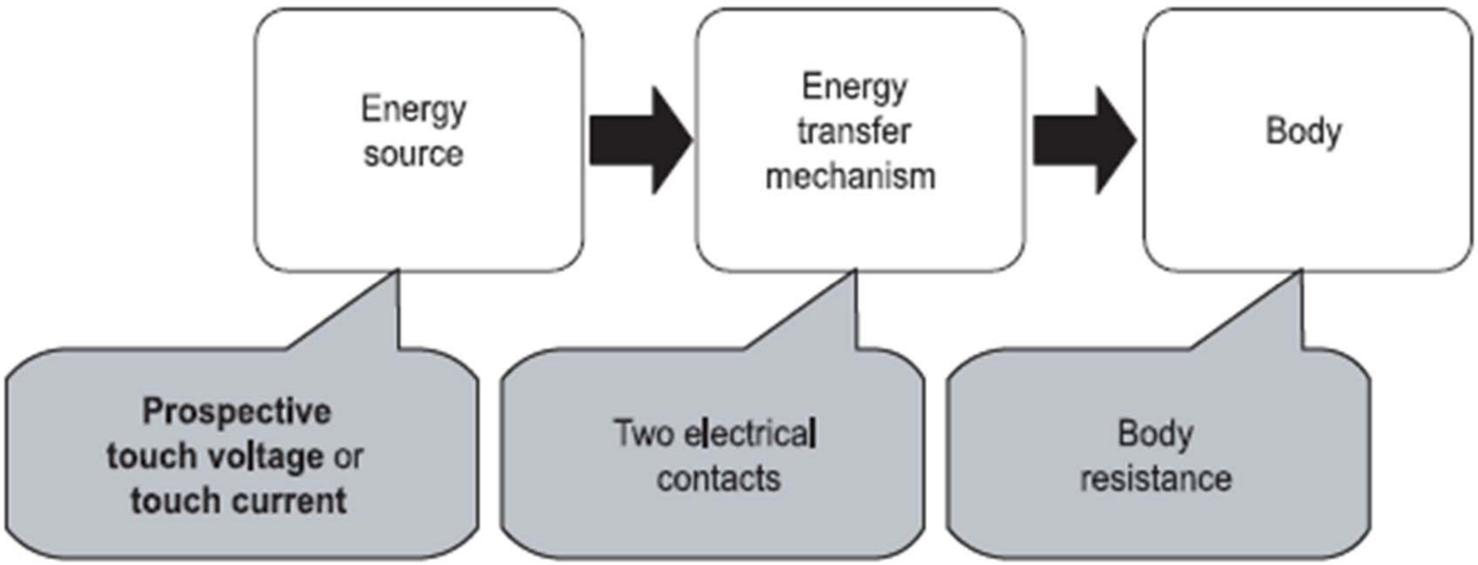
In practice, safeguard selection will take into account the:

- nature of the energy source
- intended user
- functional requirements of the equipment
- severity of injury
- similar considerations

HBSE - SAFEGUARDS

- Applying HBSE principles without some proscriptive requirements or at least prescriptive guidance requires a great deal of expertise and experience
- A great breadth of knowledge is needed to select the correct path and make the right decisions
- You especially need to know what you don’t know

EXAMPLE – Safeguard Against Electric Shock



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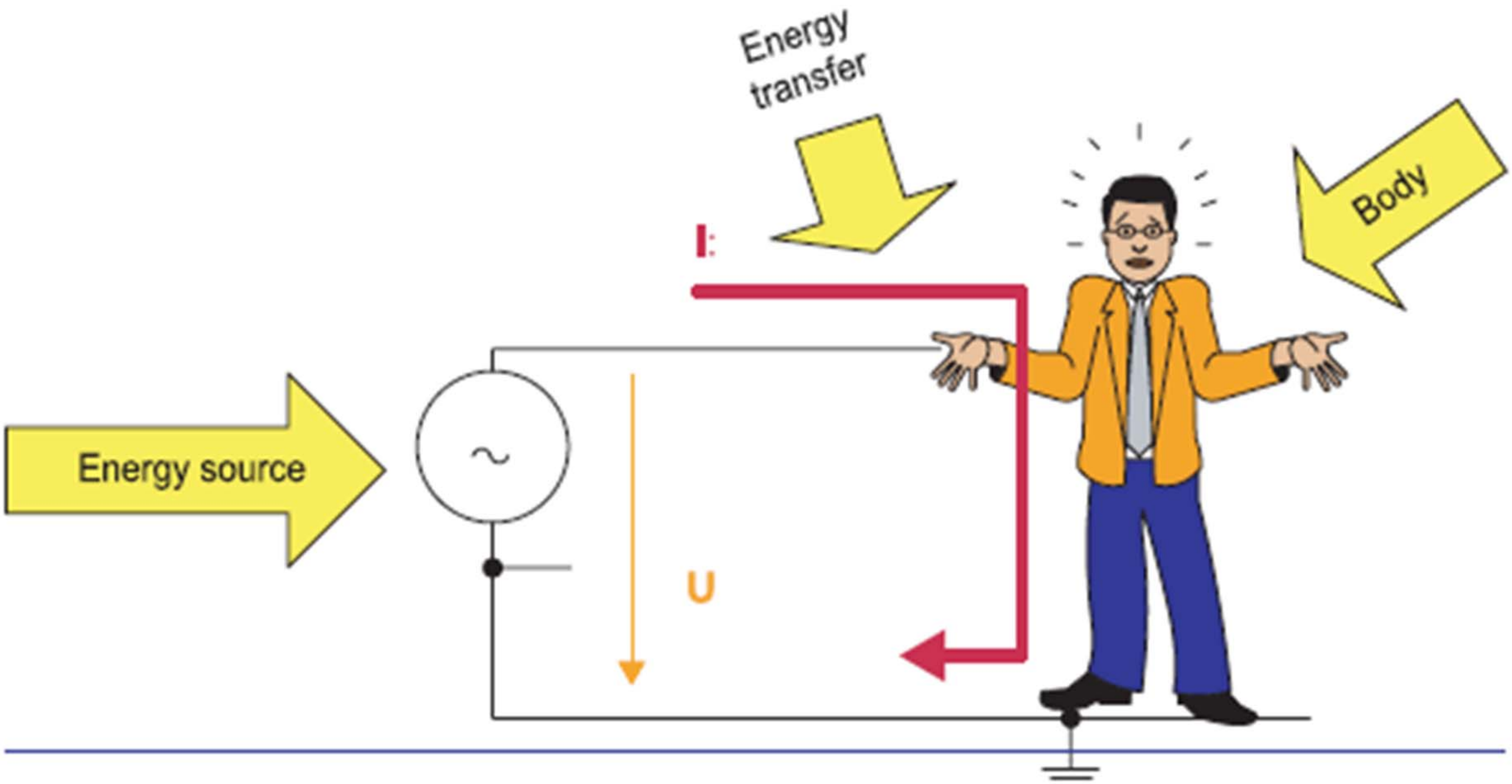

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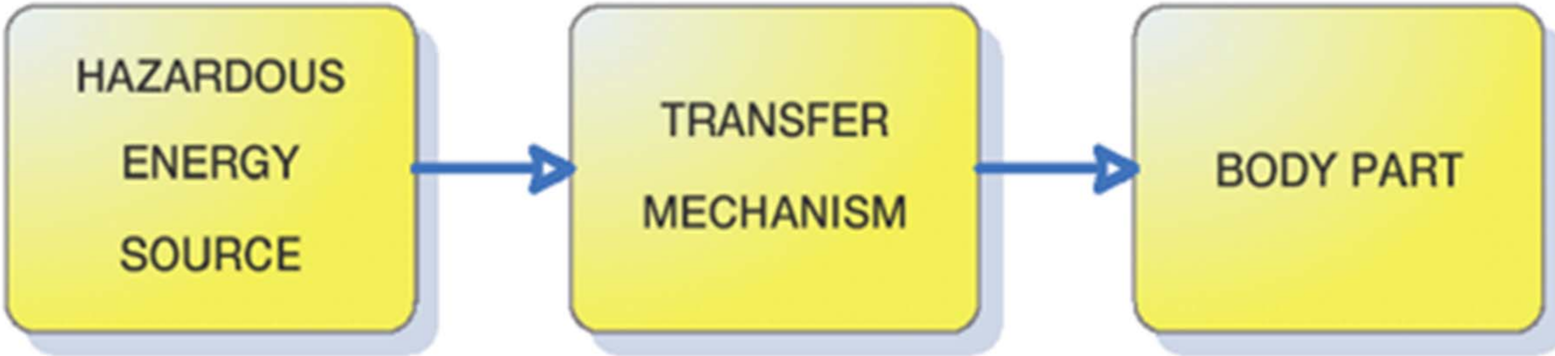
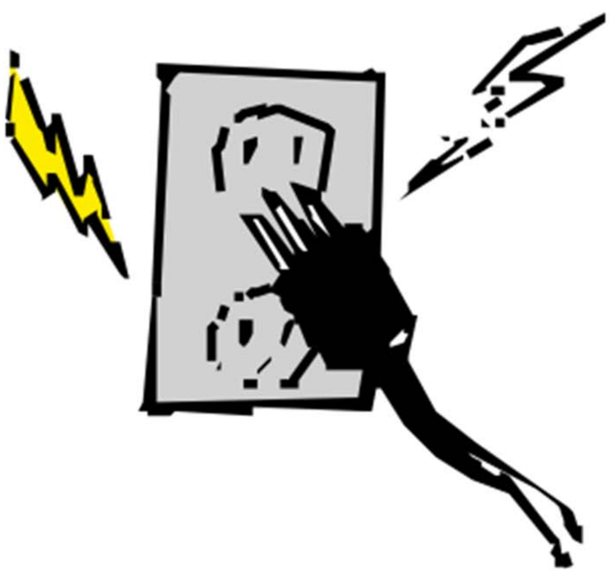


EXAMPLE – Safeguard Against Electric Shock

EXAMPLE – Safeguard Against Electric Shock

- Instructional Safeguard

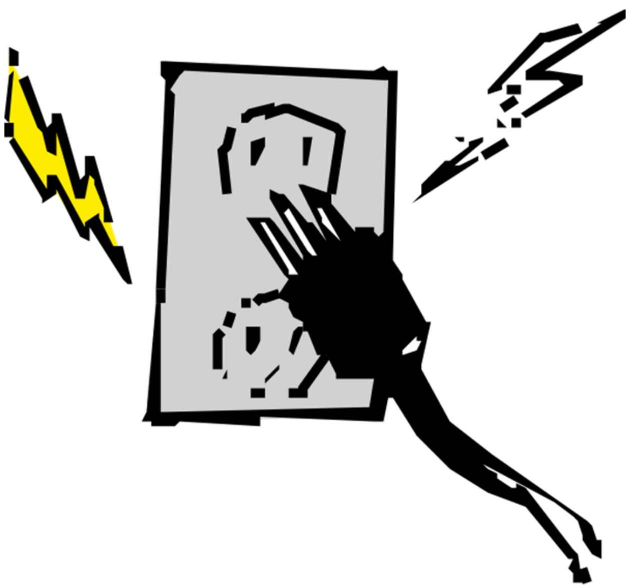


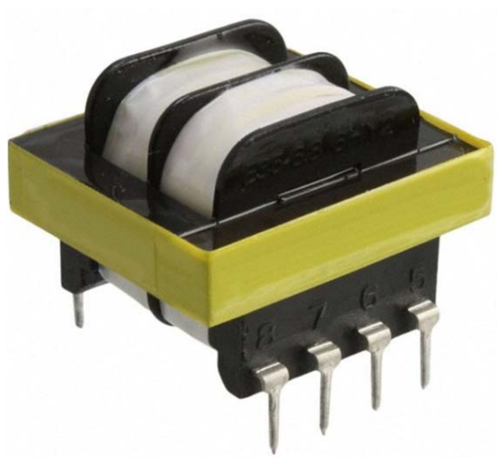
EXAMPLE – Safeguard Against Electric Shock

- Instructional Safeguard

EXAMPLE – Safeguard Against Electric Shock

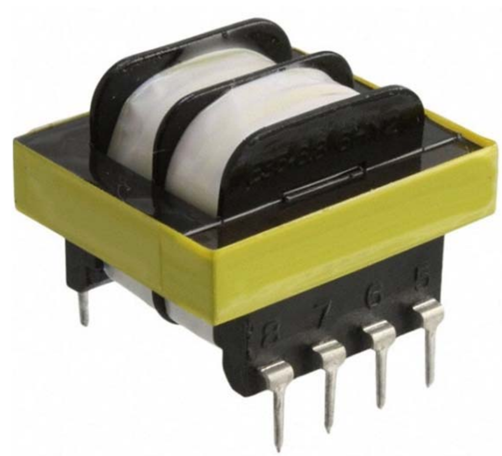
- Equipment Safeguard





EXAMPLE – Safeguard Against Electric Shock

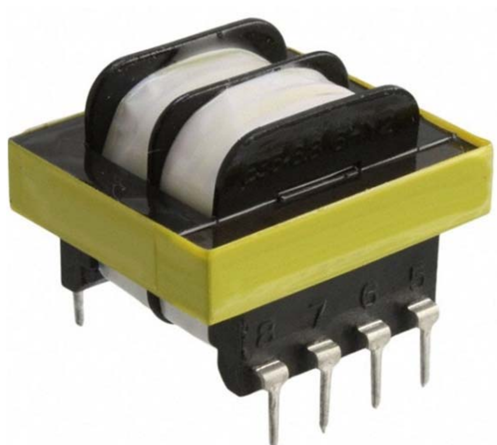
What do we know about this?



- Reduces the voltage to safe levels
- Maybe limits the current (via winding impedance)
- Isolates primary hazardous voltage at the input from “safe” secondary voltage at the output

EXAMPLE – Safeguard Against Electric Shock

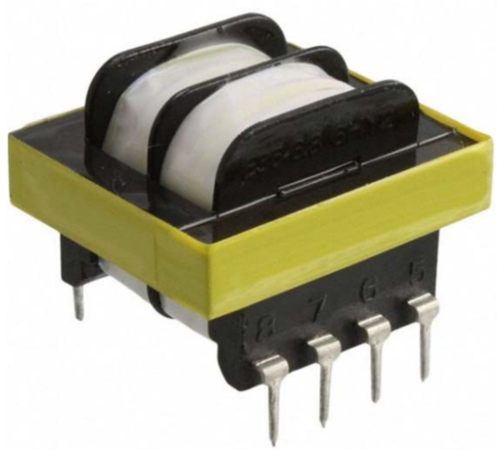
What don't we know about this?



- Are voltages and currents low enough? (What is a safe voltage??)
- Is isolation sufficient?
    - Are materials suitable?
    - Are creepage and clearance distances enough?
- Will it overheat?
- Are leakage currents sufficiently low?
- Can it withstand expected overloads and faults?
- Will the insulation degrade over time?

EXAMPLE – Safeguard Against Electric Shock

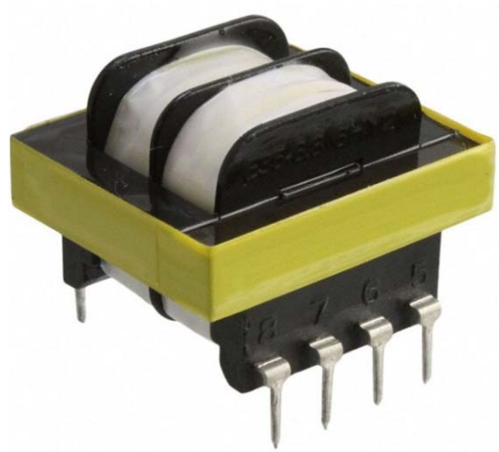
How do we determine suitability?



- Measure the voltage and current
- Dielectric voltage withstand tests
- Measure creepage and clearances
- Thermal tests
- Overload tests
- Leakage current tests
- Research or test materials or use known materials

EXAMPLE – Safeguard Against Electric Shock

Is there something we haven’t thought of?



EXAMPLE – Safeguard Against Electric Shock

Maybe not, unless……..

- SCENARIO

A transformer is used as an isolation component in power supply built into a meter socket. The power supply provides power for a NID and it is expected that the output voltages are low voltage, limited power and isolated from the primary which is connected directly to the main service drop.

EXAMPLE – Safeguard Against Electric Shock

- THE ENVIRONMENT
  - Overvoltage category is Category IV instead of Category II (Mains transient voltage 4000 V vs. 1500 V)
  - Available fault current is extremely high (>10kA vs. 200 A)
  - Operating temperatures can be expected to be much higher due to insolation (heating from the sun) and non-vented enclosure (65^{o}C is a typically specified internal ambient to take into account insolation vs. 25^{o}C)

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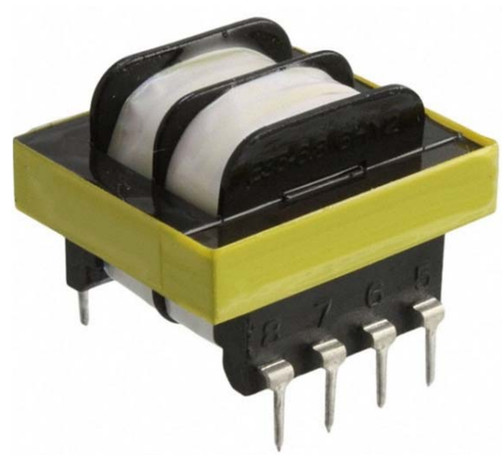
EXAMPLE – Safeguard Against Electric Shock

$$T_{operating} = 120\ ^{o}C$$



120 ^{o}C > Typical 105 ^{o}C rating of standard insulation systems

EXAMPLE – Safeguard Against Electric Shock

Select appropriate materials for the insulation system

INSULATION COMPONENT	THERMAL INDEX
Bobbin	130 ºC
Inter-winding insulation	180 ºC
Crossover lead insulation	200 ºC
Lead wire insulation	130 ºC
Magnet wire coating	150 ºC

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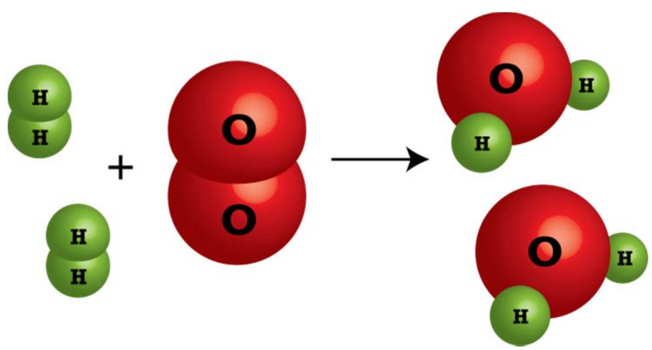
EXAMPLE – Safeguard Against Electric Shock

- The assorted materials that make up a transformer (wire, bobbin, tape, cores, silicone, etc.) can chemically interact at high temperatures
- Constitute a “thermal insulating system”
- Requires lengthy aging and temperature-cycling processes to determine if any of the constituent materials interact in a manner that forms contaminants
- UL 1446, "Systems of Insulating Materials - General."



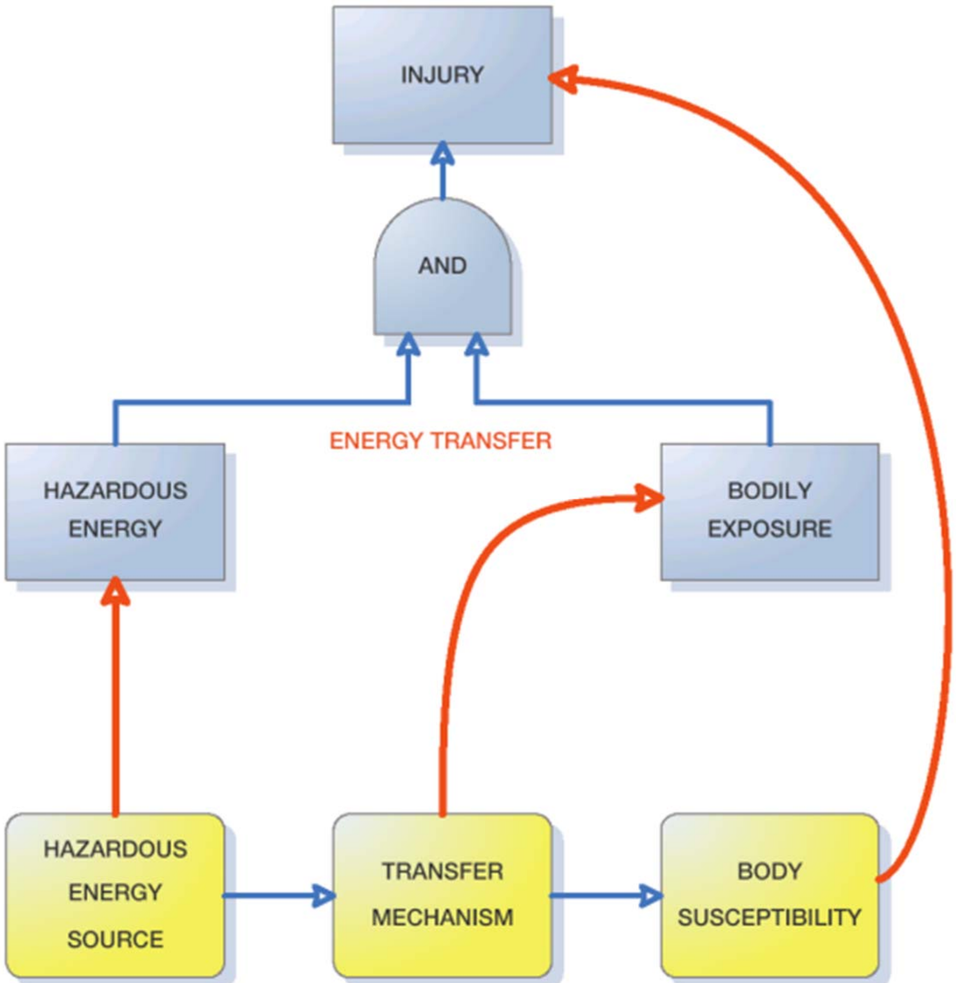
EXAMPLE – Safeguard Against Electric Shock

- Today's complex electrical applications demand greater diligence in verifying that individual insulation materials can perform together in shared environments. This allows us to determine if components react chemically at certain maximum temperatures, which may cause product failure or other hazards to occur.

- The evaluation of an insulation system in accordance with UL 1446 is primarily a compatibility evaluation which determines the ability of materials not to degrade when placed in close proximity to each other and when subjected to elevated temperatures.

Fault Trees

HBSE – INJURY FAULT TREE



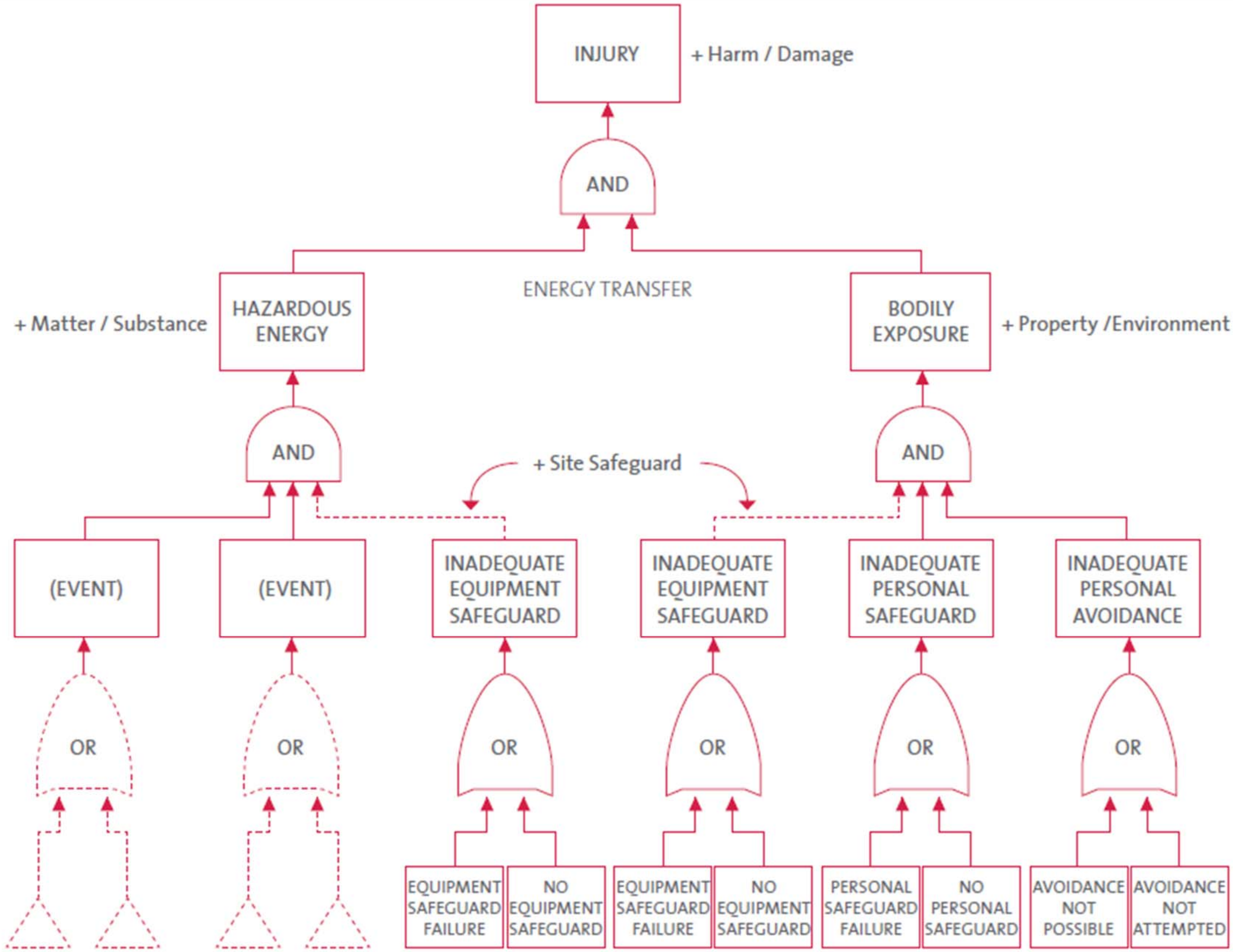
Fault Tree Analysis

- A fault tree is a diagram that displays the logical interrelationship between the basic causes of the hazard
- Fault tree analysis can be simple or complex depending on the system in question. Complex analysis involves the use of Boolean algebra to represent various failure states

Fault Tree Analysis

- The first stage is to select the hazard or top event that is to be analyzed
- The tree is structured so that the hazard appears at the top. It is then necessary to work downwards, firstly by identifying causes that directly contribute to this hazard
- When all the causes and sub-causes have been identified, the next stage is to construct the fault tree

HBSE – INJURY FAULT TREE



Examples

Example: Primary Protector

Primary Protector Example

Hazardous Energy Source

Transfer Mechanism

Body Part

Primary Protector Example

Hazardous Energy Source

Transfer Mechanism

Body Part

Primary Protector Example

Hazardous Energy Source

Transfer Mechanism

Body Part

Primary Protector Example

Hazardous Energy Source

Transfer Mechanism

Body Part

Primary Protector Example

Hazardous Energy Source

+

Transfer Mechanism

+

Body Part

Primary Protector Example

Hazardous Energy Source

Safeguard

Body Part

Personal Protection Safeguard

Instructional Safeguard

13. During thunderstorms, avoid using telephones except cordless types. There may be a remote risk of an electric shock from lightning.
14. Do not use this unit to report a gas leak, when in the vicinity of the leak.

SAVE THESE INSTRUCTIONS

HBSE – 3-Block Model for Safety

A safeguard provides the following:

- Attenuates the energy
- Impede the energy (slows rate of transfer)
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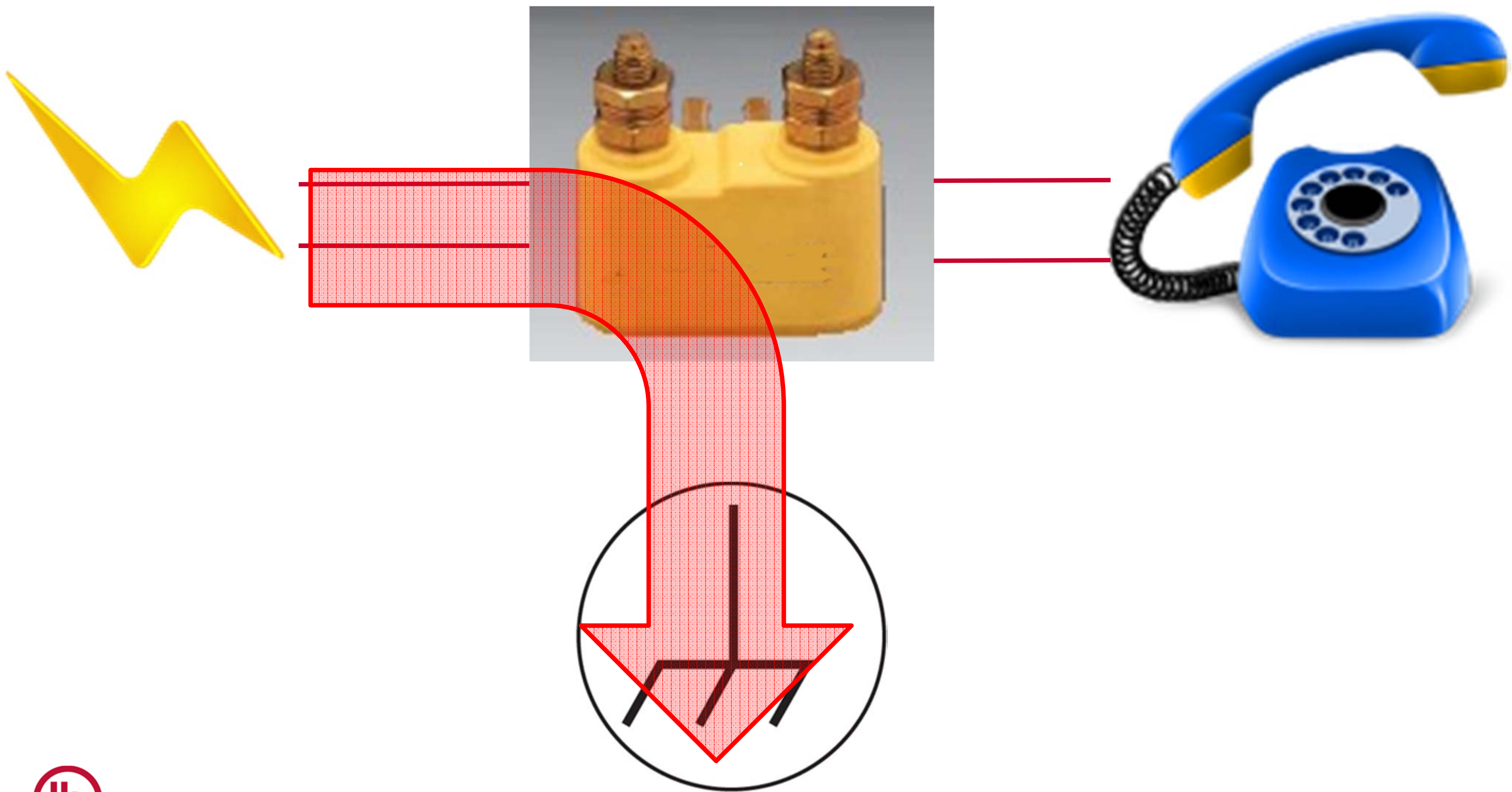
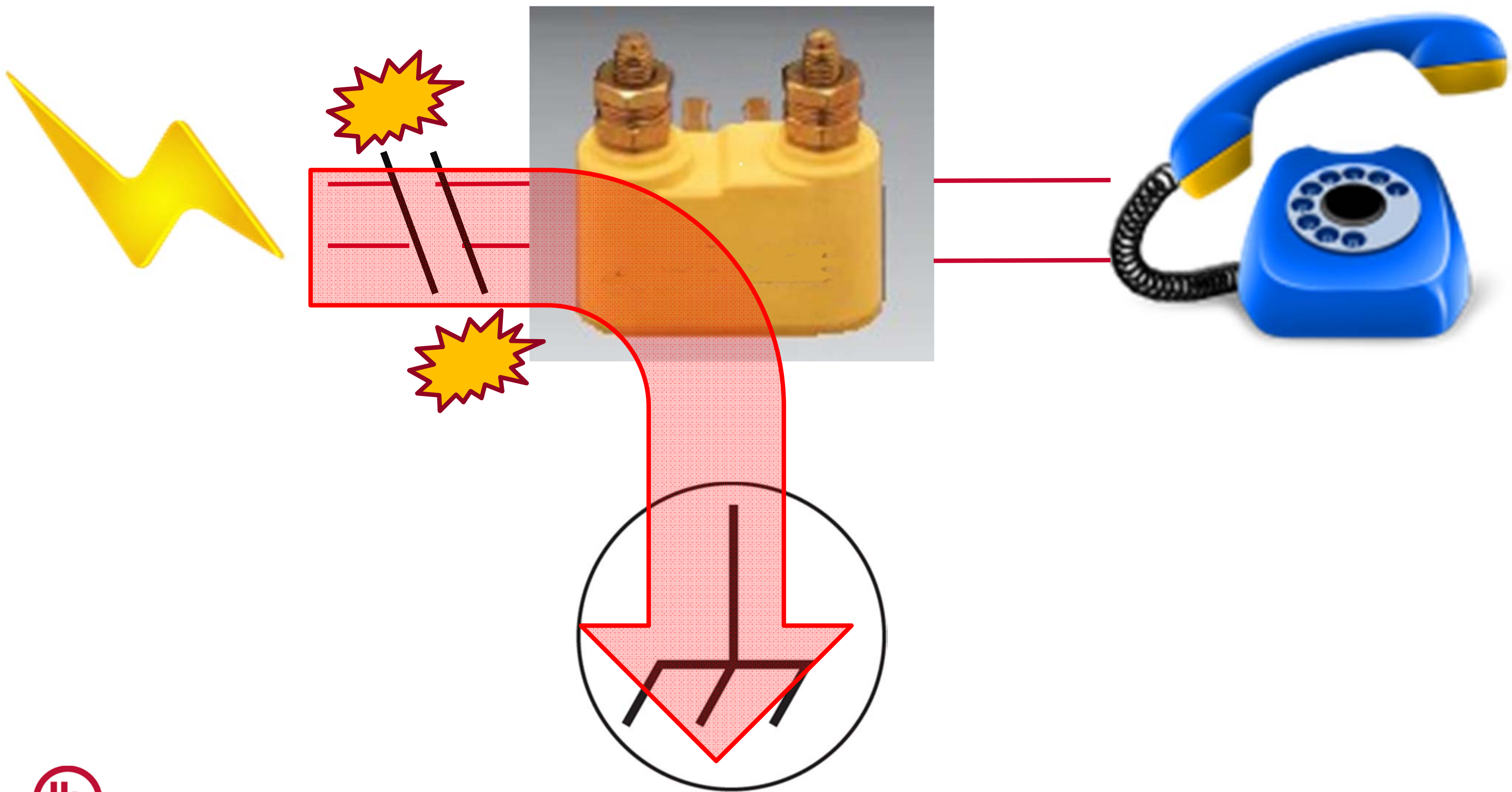
Primary Protector

Divert the energy (change its direction)



Primary Protector

Disconnect or disable the energy source



Primary Protector Example
HBSE - SAFEGUARDS

DURESS

- **D**urability
- **U**sability
- **R**eliability
- **E**fficacy
- **S**uitability
- **S**calability

Primary Protector Example
HBSE - SAFEGUARDS

DURESS

- **D**urability = GR-974-CORE
- **U**sability = GR-974-CORE
- **R**eliability = GR-974-CORE
- **E**fficacy = GR-974-CORE, UL497
- **S**uitability = ??
- **S**calability = GR-974-CORE, UL497, NEC [NOTE 1]

NOTE 1 –Often installation dependent

Primary Protector Example

- Determine the Severity of Injury
  - Identify the hazards
  - Imagine accident scenarios to determine the injuries to which the hazards can lead
  - Determine the severity of these injuries (Slight, Moderate, Serious, Very Serious)

ESD

ESD

Primary Protector Example
Assess the Probability of Harmful Energy Transfer

Probability = probability that the hazard occurs with the foreseen severity during the foreseeable lifetime of the product

Primary Protector Example
Assess the Probability of Harmful Energy Transfer

Determine the Probability of the injury to occur

- Determine for each injury in each scenario the steps that are necessary for the injury to occur with the foreseen severity
- Estimate the probabilities of each of these steps.
- The overall probability is the multiplication of each of these sub-probabilities

Primary Protector Example
Assess the Probability of Harmful Energy Transfer

Choose the probability class

Almost certain, might well be expected > 1/1
Quite possible > 1/10
Unusual but possible > 1/100
Only remotely possible > 1/1,000
Conceivable, but highly unlikely > 1/10,000
Practically impossible > 1/100,000
Impossible unless aided > 1/1,000,000
(Virtually) Impossible < 1/1,000,000

Primary Protector Example
Assess the Probability of Harmful Energy Transfer

Which factors can influence the probability ?

- Product properties including the presentation and the presence of warnings
- Intended users and foreseeable users
  - Children, elderly, disabled, professional
- Intended use and foreseeable misuse
- Frequency and duration of use
- Hazard recognition and ensuing protective behavior and equipment
- Consumer behavior in case of an incident
- Consumer's cultural background

Primary Protector Example
Assess the Probability of Harmful Energy Transfer

How do you determine the probabilities?

- Manufacturers with a quality system should be able to give a lot of useful statistics
- When accident statistics for specific products exist, they can directly be used to determine the probability
- A search in newspapers or on the internet might help to find some useful information
- Even finding nothing might help to estimate the probability.

Primary Protector Example

Probability of Injury Without Protector

What do I need to happen (or not happen) for the injury to occur?

- Lightning striking telephone line
  Quite possible > 1/10
- Person talking on the phone when lightning strikes
  Unusual but possible > 1/100

Probability = 1/10 X 1/100 = 1/1,000

Primary Protector Example

Probability of Injury With Protector

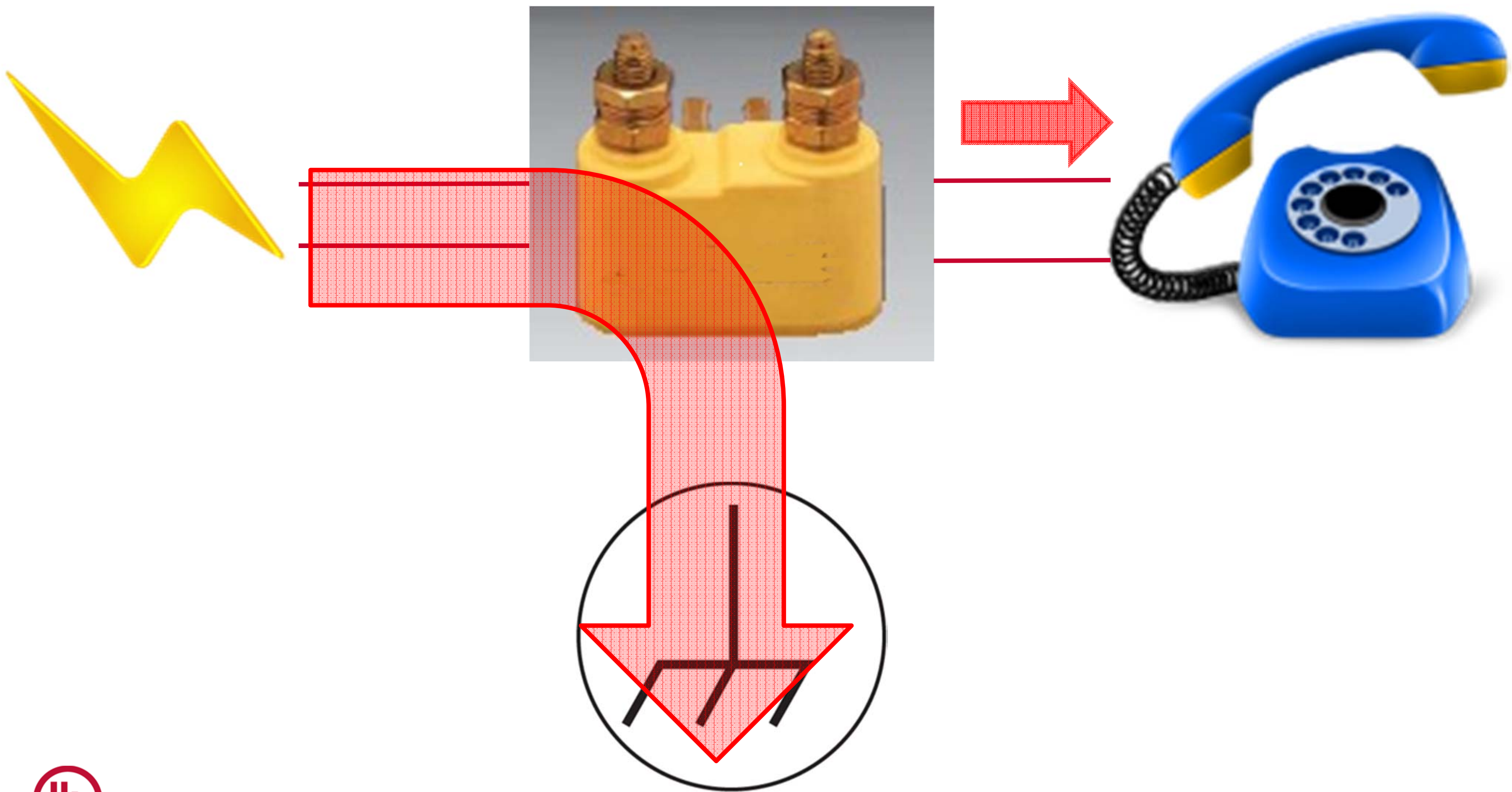
What do I need to happen (or not happen) for the injury to occur?

- Lightning striking telephone line
  Quite possible > 1/10
- Protector fails to suppress voltage
  Practically impossible > 1/100,000
- Person talking on the phone when lightning strikes
  Unusual but possible > 1/100

Probability = 1/10 X 1/100,000 X 1/100 = 1/100,000,000

Primary Protector Example

Some residual voltage will get through



Primary Protector Example

Probability of Injury With Protector

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- Person talking on the phone when lightning strikes
  Unusual but possible > 1/100

Probability = 1/10 X 1/10,000 X 1/100 = 1/10,000,000

Was the protector installed Correctly

Primary Protector Example

Probability of Injury With Protector

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- Lightning striking telephone line
  Quite possible > 1/10
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Instructional Safeguard

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SAVE THESE INSTRUCTIONS

Probability of Injury With Protector

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Probability = 1/10 X 1/1,000 X 1/1,000 = 1/10,000,000

Primary Protector Example

Probability of Injury With Protector

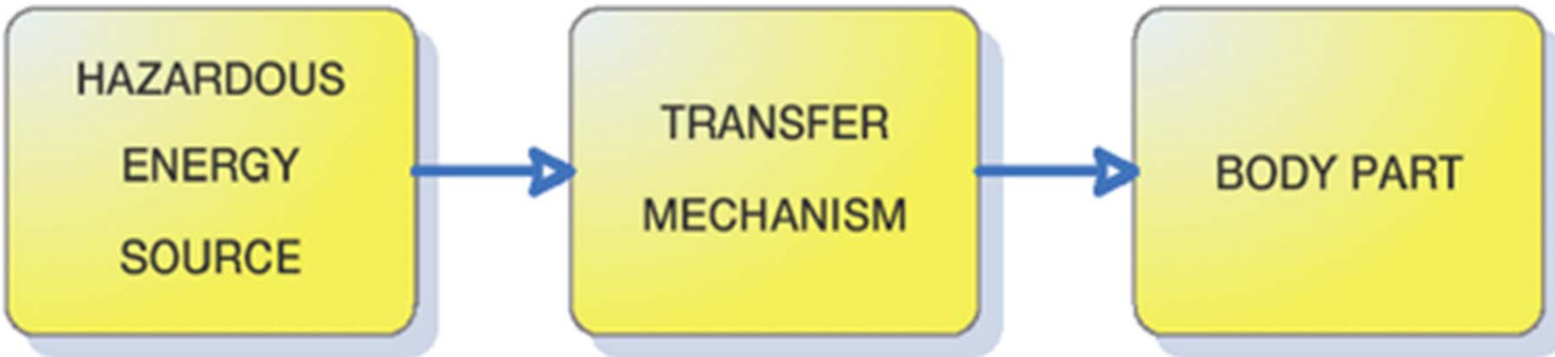
What do I need to happen (or not happen) for the injury to occur?

- Lightning striking telephone line
  Quite possible > 1/10
- Protector fails to suppress voltage
  Only remotely possible > 1/1,000
- Person talking on the phone when lightning strikes
  Only remotely possible > 1/1,000
- Person grounded when lightning strikes
  Quite possible > 1/10

Probability = 1/10 X 1/1,000 X 1/1,000 X 1/10 = 1/100,000,000

Example: Optical Fiber with a Metallic Strand

Optical Fiber with a Metallic Strand

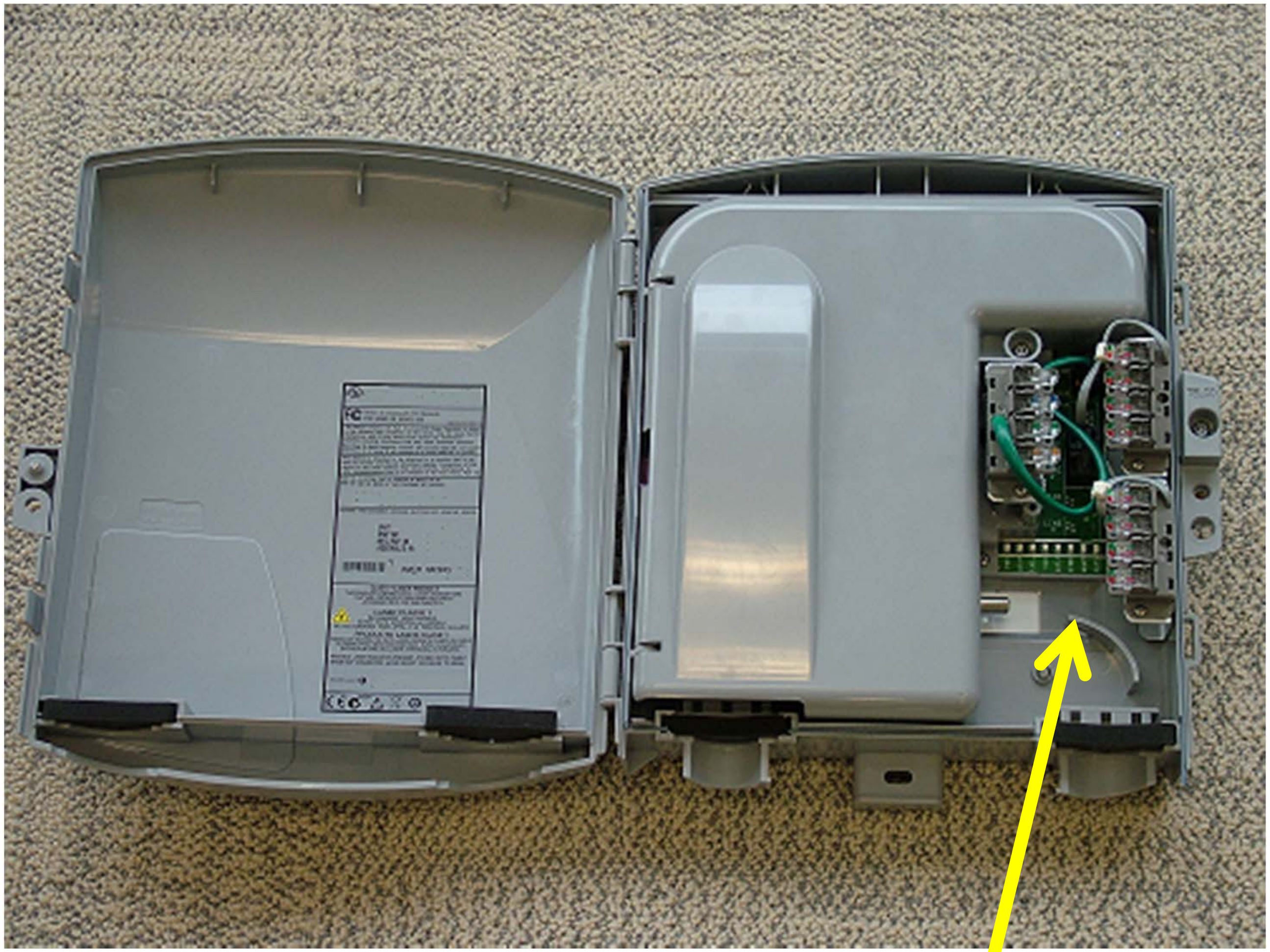


Hazardous Energy Source

Transfer Mechanism

Body Part

Optical Fiber with a Metallic Strand



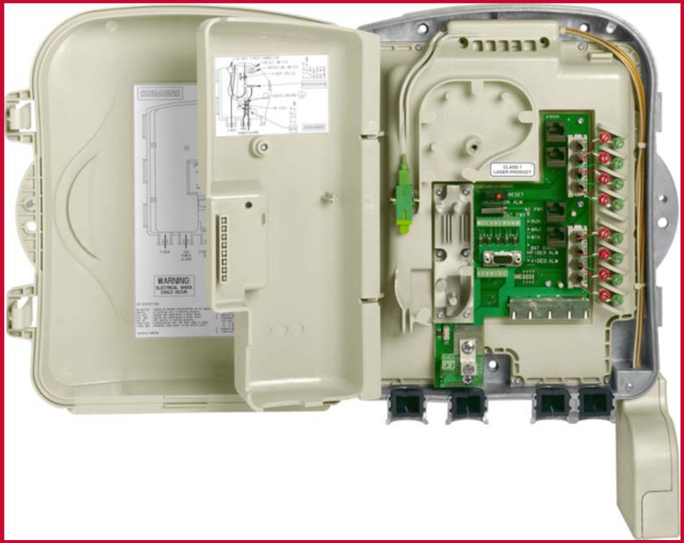
Metallic connections to the inside of the premises

Optical fiber with a Metallic Strand

770.93 Grounding or Interruption of Non–Current- Carrying Metallic Members of Optical Fiber Cables.

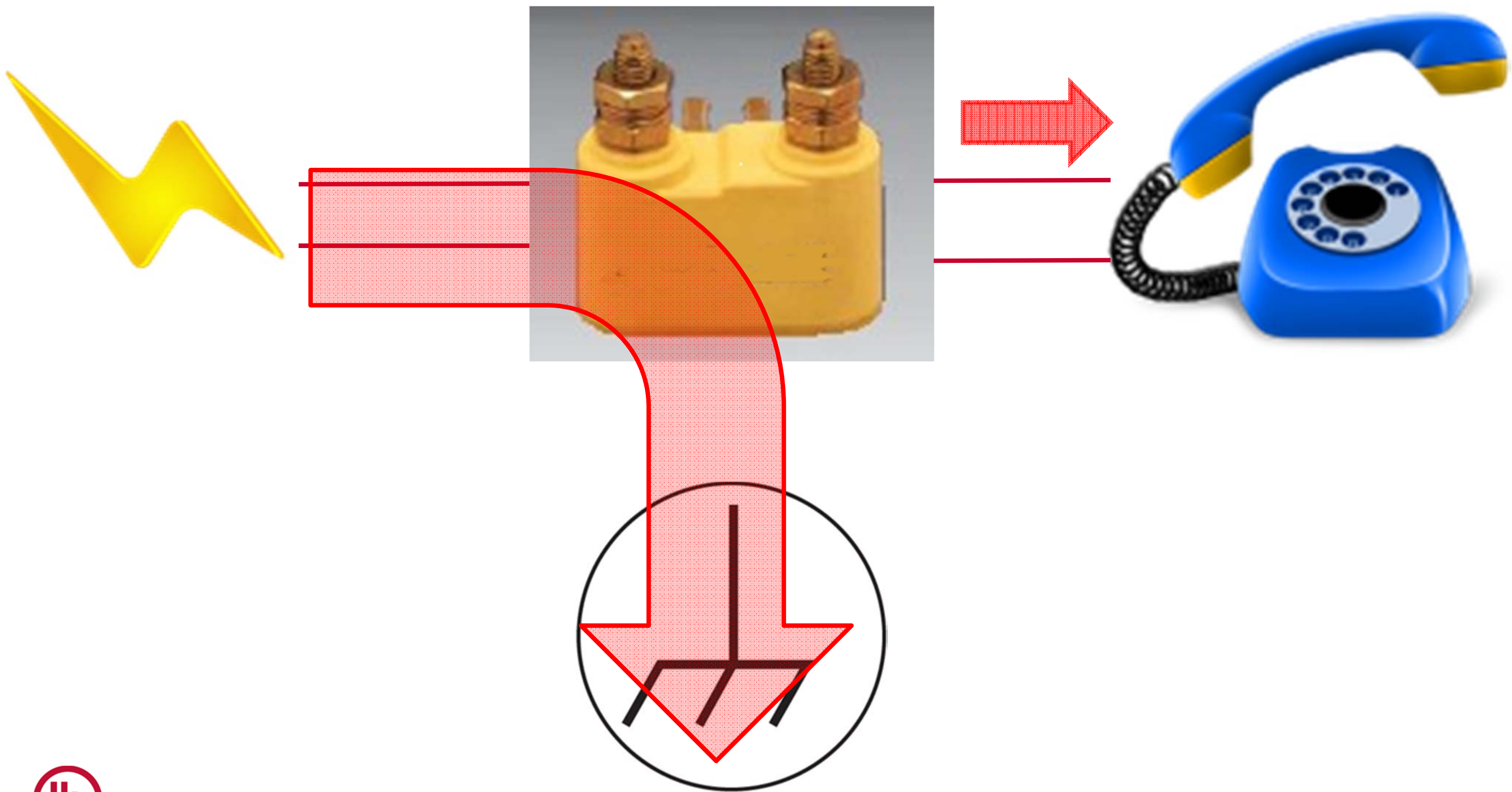
- Effective grounding
- Isolation

Example: Secondary Protection



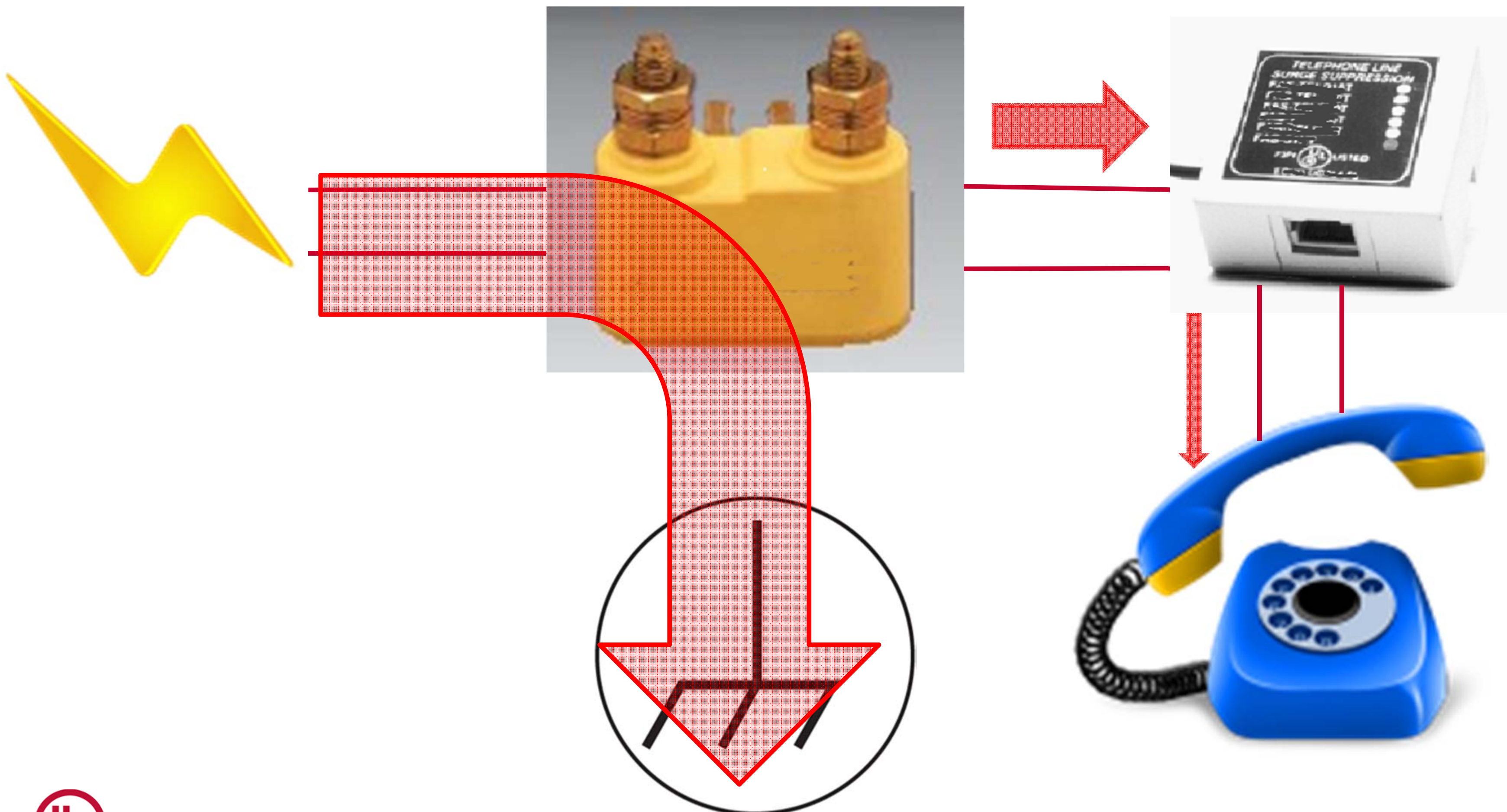
Primary Protector

Some residual voltage will get through



Secondary Protectors

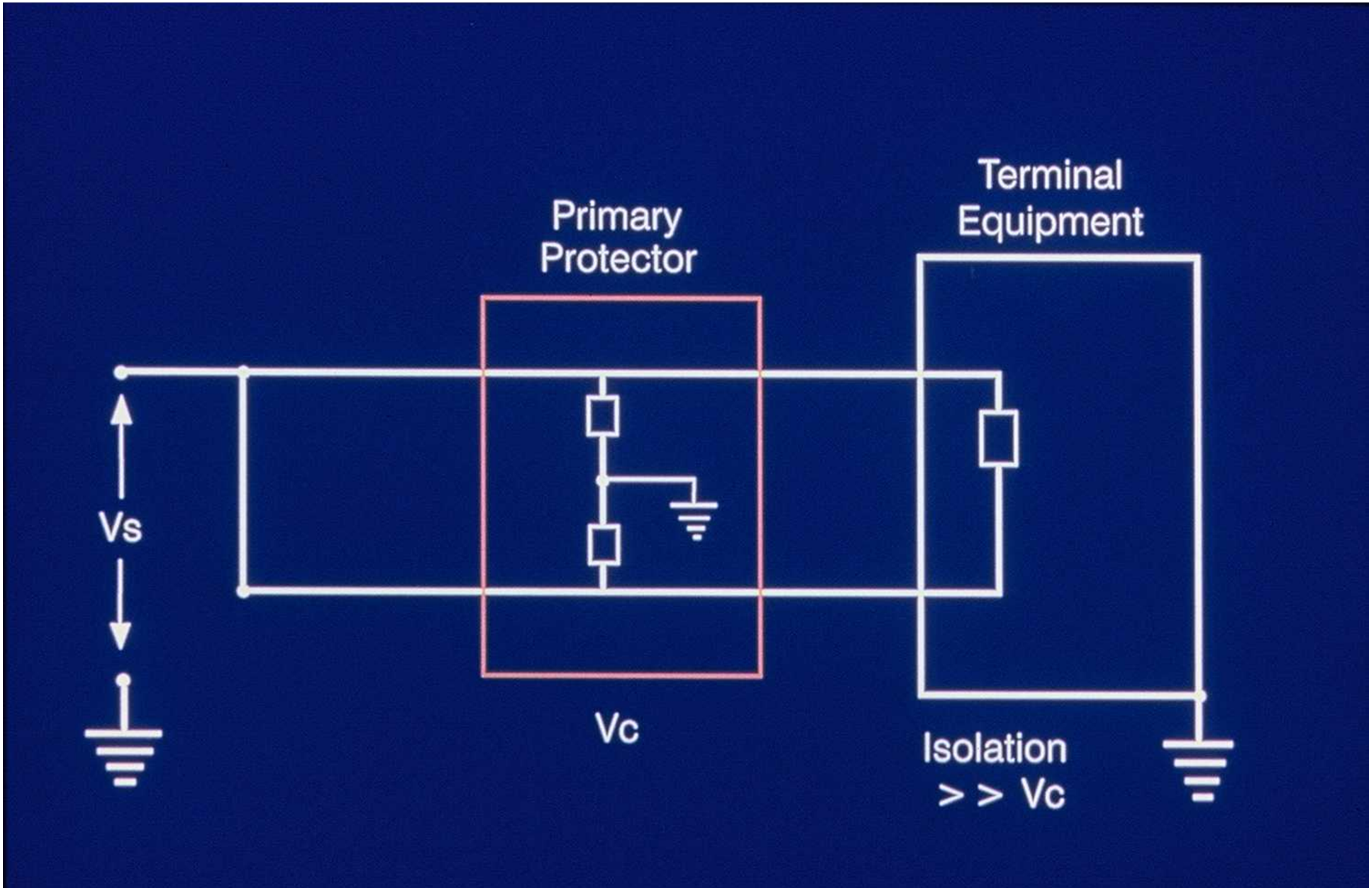
Reduces the residual voltage (at least in theory)



Secondary Protector Example

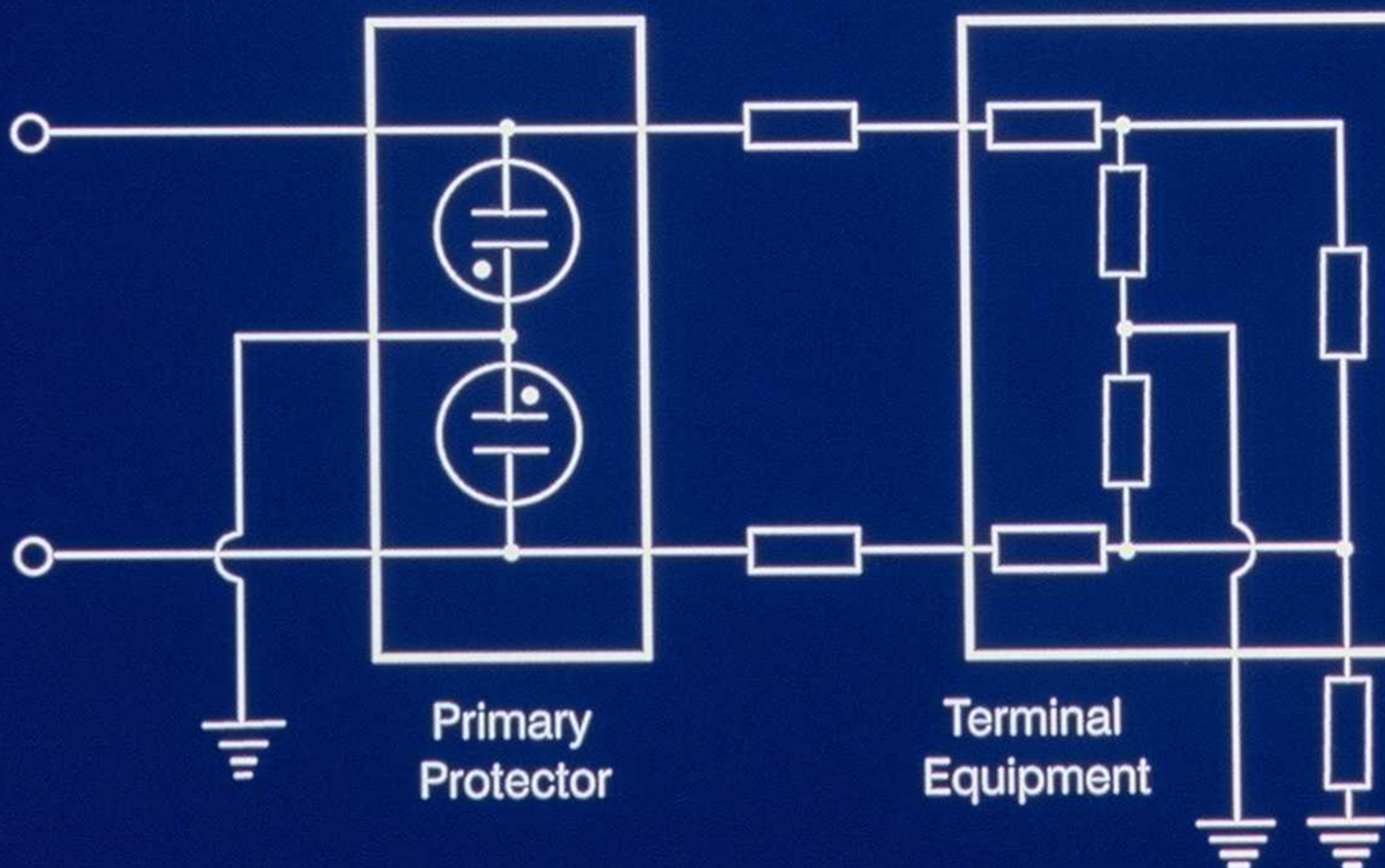
HBSE - SAFEGUARDS

Efficacy — protection should be able to effectively perform the needed safety function, without introducing or increasing other hazards (fix one problem but create another)

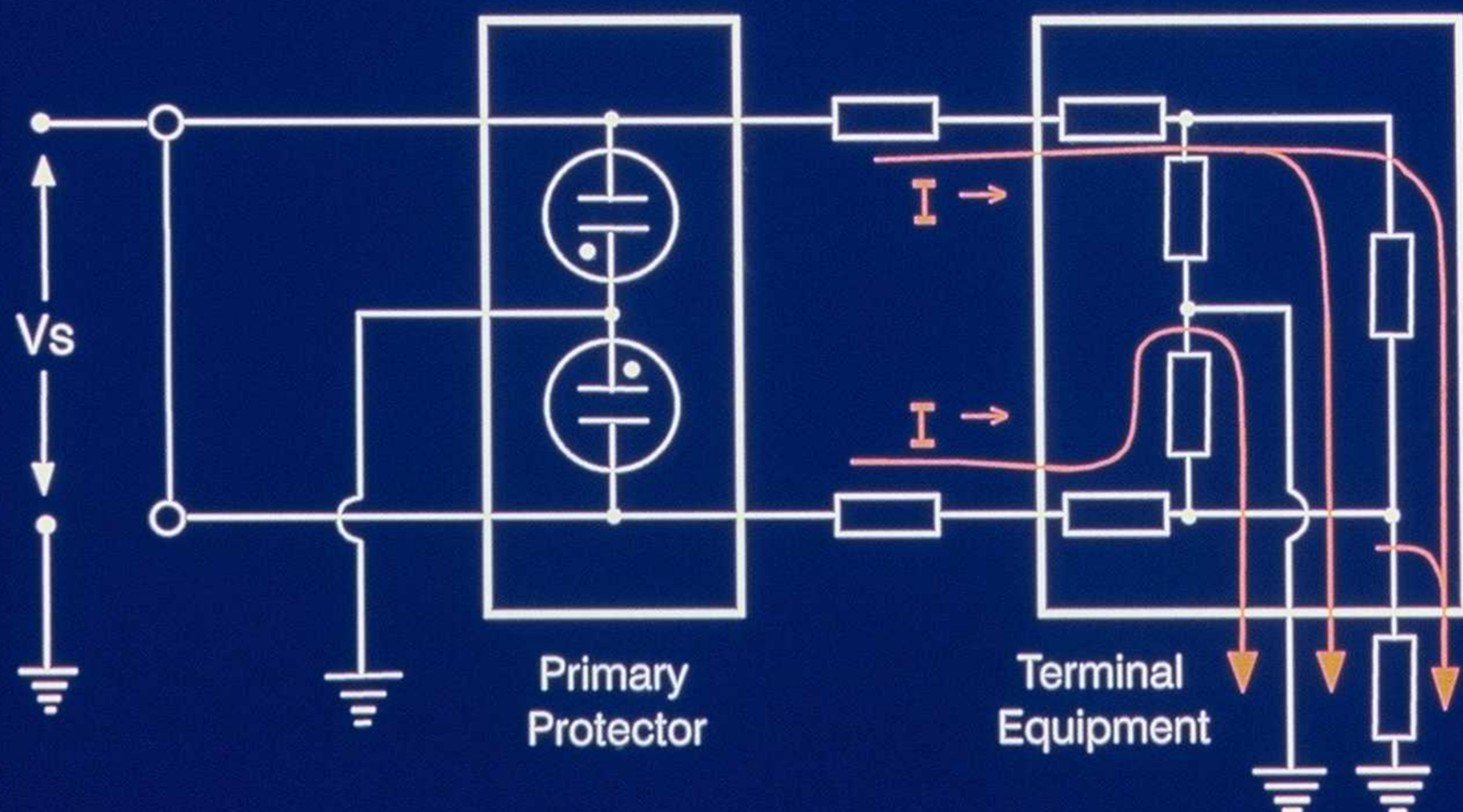


Terminal
Equipment
Primary
Protector
Vs
Vc
Isolation
> > Vc

Elements of a Typical Telecommunication Circuit



Common Mode Condition



Secondary Protector Example

UL 497A – Secondary protectors

4.2 A secondary protector **shall include overcurrent protection** which will fuse, limit, or extinguish at currents less than the current-carrying capacity of indoor communications wire, cable or terminal equipment. Any overvoltage protection or grounding connection shall be connected on the equipment terminal side of the secondary protector overcurrent protection system.

Failure Modes and Effects Analysis

Failure Modes and Effects Analysis

- For each component's functions, every conceivable mode of failure is identified and recorded.
- It is also common to rate the failure rate for each failure mode identified.
- The potential consequences for each failure must be identified along with its effects on other equipment, components within the rest of the system.
- It is then necessary to record preventative measures that are in place or may be introduced to correct the failure, reduce its failure rate or provide some adequate form of detection.

Failure Modes and Effects Analysis

FMEA worksheet

Name of system..
Mode of operation..
Sheet No...
Date...
Name of analyst...

References...
System block diagrams...
....
....
Drawings...

Equipment name or number	Function	Ident. No.	Failure mode	Failure cause	Failure effect Local effect End effect	Failure detection	Corrective action	Severity of failure effect	Probability of failure (If applicable)	Remarks	

ENERGY SOURCE CLASSIFICATIONS

Energy source classifications
Class 1 Energy Source

An energy source with levels

- not exceeding class 1 limits under
  - **normal operating conditions** and
  - **abnormal operating conditions** that do not lead to a **single fault condition**,
- not exceeding class 2 limits under **single fault conditions**.

Energy source classifications
Class 1 Energy Source

Under normal operating conditions the energy in a class 1 source, in contact with a body part, may be detectable, but is not painful nor is it likely to cause an injury

Under **single fault conditions**, a class 1 energy source, under contact with a body part, may be painful, but is not likely to cause injury

For fire, the energy in a class 1 source is not likely to cause ignition

Energy source classifications
Class 2 Energy Source

An energy source with levels

- exceeding class 1 limits, and,
- not exceeding class 2 limits under **normal operating conditions**, **abnormal operating conditions**, or **single fault conditions**

The energy in a class 2 source, under contact with a body part, may be painful, but is not likely to cause an injury

For fire, the energy in a class 2 source can cause ignition under some conditions

Energy source classifications
Class 3 Energy Source

An energy source with levels

- exceeding class 2 limits under **normal operating conditions**, **abnormal operating conditions**, or **single fault conditions, or**
- declared to be a class 3 source

The energy in a class 3 source, under contact with a body part, is capable of causing injury

For fire, the energy in a class 3 source may cause ignition and the spread of flame where fuel is available

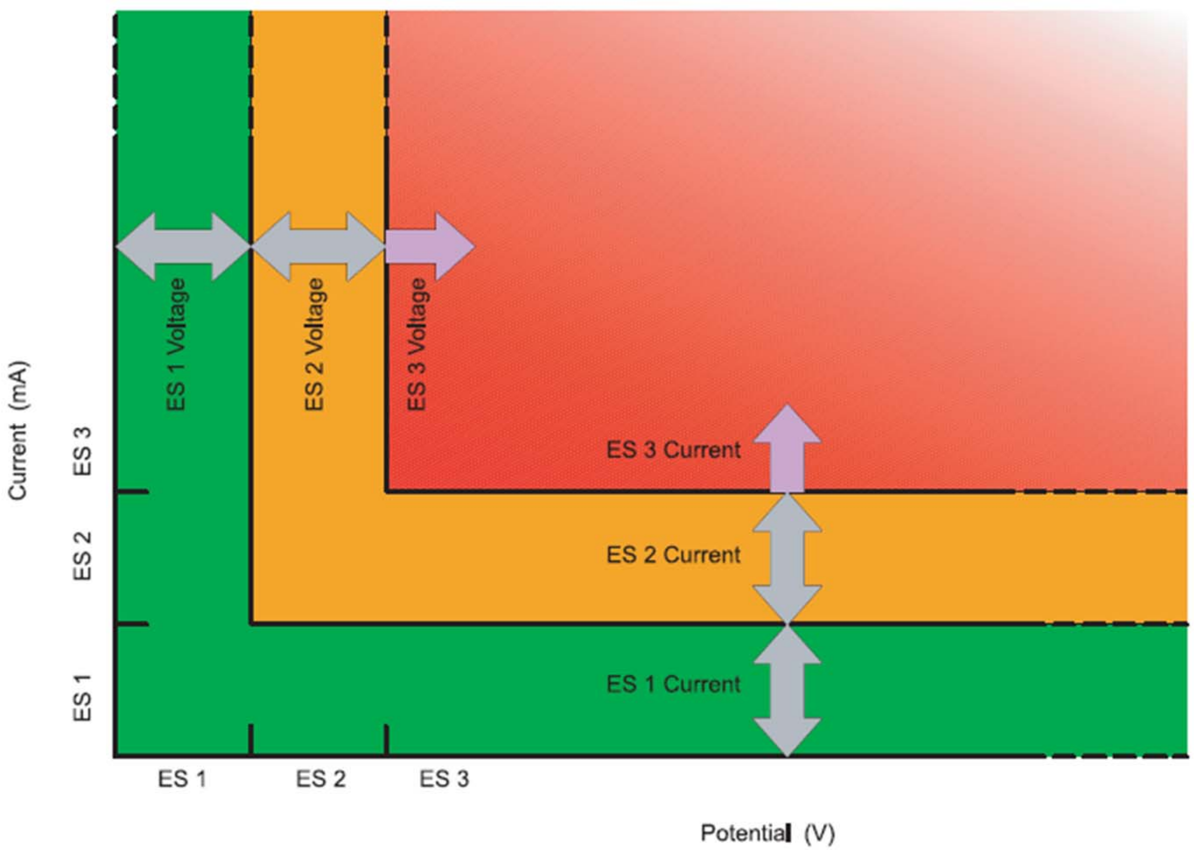
Energy source classifications
Electrically-caused injury

Classification and limits of electrical energy sources (ES)

- ES1 is a class 1 electrical energy source
- ES2 is a class 2 electrical energy source
- ES3 is a class 3 electrical energy source

Energy source classifications
Electrically-caused injury

ES limits depend on both voltage and current



Energy source classifications
Electrically-caused fire

Classification of power source (PS) circuits

- PS1
  - Does not exceed 500 W measured during the first 3 s; and
  - Does not exceed 15 W measured after 3 s
- PS2
  - exceeds PS1 limits; and
  - does not exceed 100 W measured after 5 s
- PS3
  - exceeds PS2 limits
  - power source has not been classified

Energy source classifications
Electrically-caused fire

Classification of potential ignition sources(PIS)

Arcing PIS

An arcing PIS is a location with the following characteristics

- an open circuit voltage (measured after 3 s) across an open conductor or opening electrical contact exceeding 50 V (peak) a.c. or d.c.; and
- the product of the peak of the open circuit voltage (V_p) and the measured r.m.s. current (I_{rms}) exceeds 15 (that is, V_p ´ Irms >15)
- An arcing PIS is considered not to exist in a PS1 because of the limits of the power source

Energy source classifications
Electrically-caused fire

Classification of potential ignition sources(PIS)

Resistive PIS

A resistive PIS is any part in a PS2 or PS3 circuit that:

- has a power capability to dissipate more than 15 W measured after 30 s of normal operation; or
- under single fault conditions:
  - has a power exceeding 100 W measured during the 30 s immediately after the introduction of the fault if electronic circuits, regulators or PTC devices are used; or
  - has an available power exceeding 15 W measured 30 s after the introduction of the fault
- A resistive PIS is considered not to exist in a PS1 because of the limits of the power source

Energy source classifications
Mechanically-caused injury

Mechanical energy source classifications

- MS1 Does not cause pain or injury
- MS2 Does not cause injury but may be painful
- MS3 May cause injury

EXAMPLES

- Sharp edges and corners
- Moving fan blades
- Loosing, imploding or exploding parts
- Equipment mass
- Wall/ceiling mounted equipment

Energy source classifications
Radiation

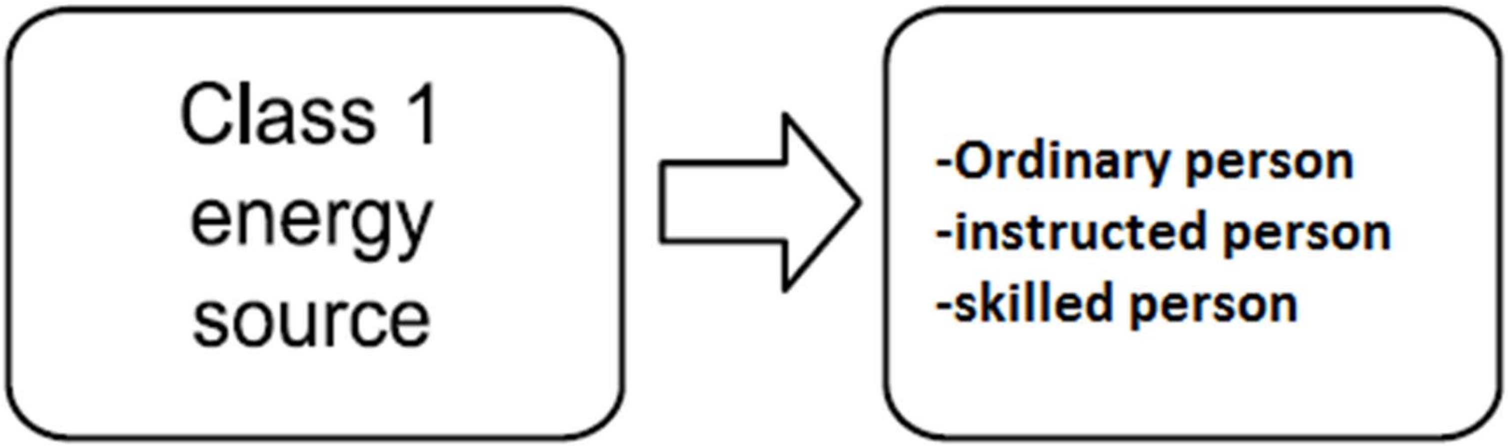
Radiation energy source classifications

- RS1 The energy is undetectable to detectable but not painful
- RS2 the energy may be detectable to painful. Exposure to RS2 is acceptable within given exposure limits and related short time periods (dose rates). Does not cause injury but may be painful
- RS3 the energy, even at short exposure (instantaneous power or power density), is considered injurious

Protection against energy sources
Class 1

- No **safeguards** need be interposed between a class 1 energy source and an **ordinary person,** an **instructed person** or a **skilled person**
- A class 1 energy source may be **accessible** to an **ordinary person**.

Protection against energy sources
Class 1

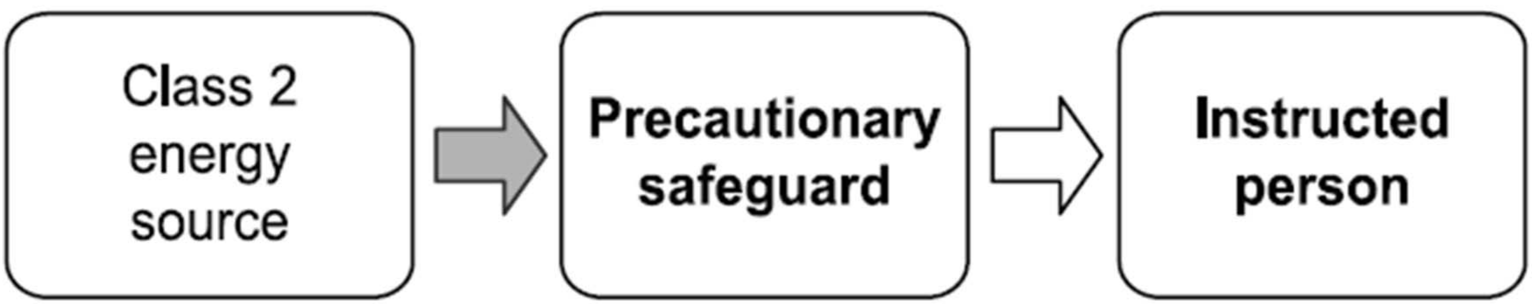


Protection against energy sources
Class 2

- During **normal operating conditions** at least one **basic safeguard** shall be interposed between a class 2 energy source and an **ordinary person**

Protection against energy sources
Class 2

- During **instructed person** servicing, the **equipment safeguards** against a class 2 energy source may be removed or defeated.
- An **instructed person** is presumed to use precaution as a **safeguard** against a class 2 energy source

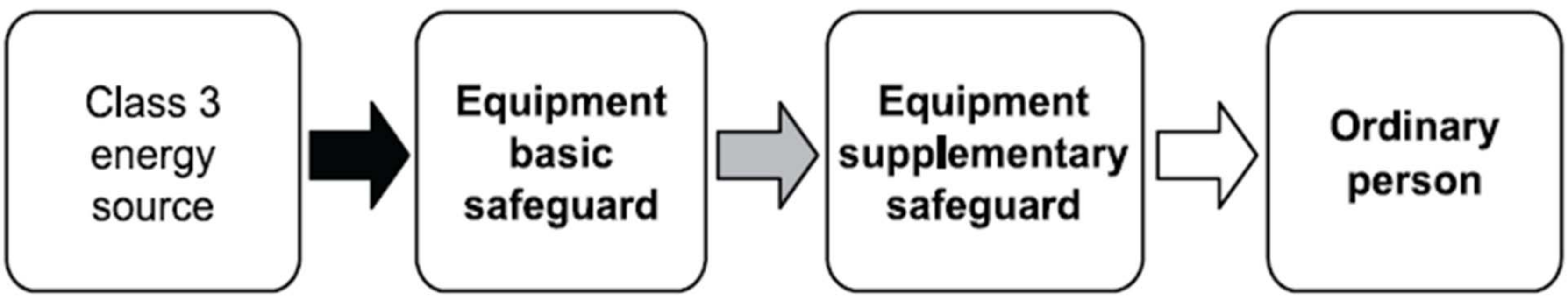


Protection against energy sources
Class 2

- During **skilled person** servicing, the **equipment safeguards** against a class 2 energy source may be removed or defeated.
- A **skilled person** is presumed to use skill as a **safeguard** against a class 2 energy source

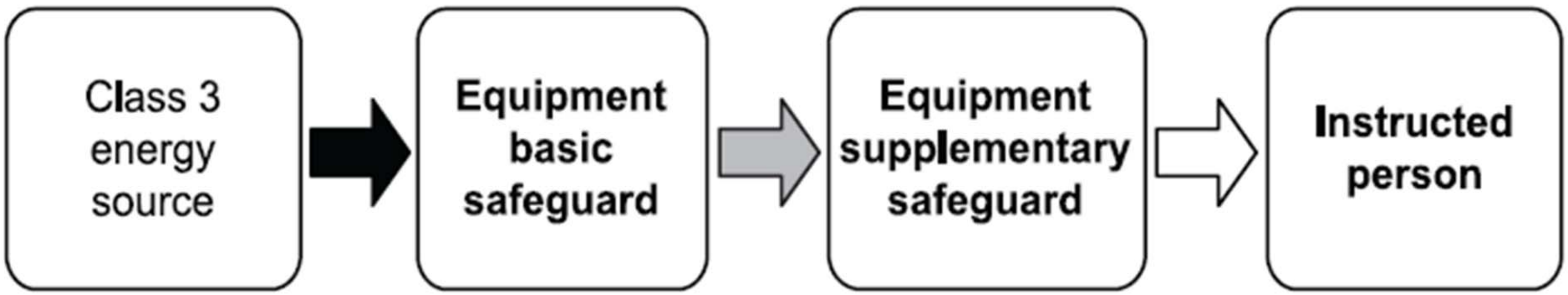
Protection against energy sources
Class 3

- An **equipment basic safeguard** and an **equipment supplementary safeguard** (**double safeguard**) or an **equipment reinforced safeguard** shall be interposed between a class 3 energy source and an **ordinary person**



Protection against energy sources
Class 3

- An **equipment basic safeguard** and an **equipment supplementary safeguard** (**double safeguard**) or a **reinforced safeguard** shall be interposed between a class 3 energy source and an **instructed person**



Protection against energy sources
Class 3

- During **skilled person** servicing, the **equipment safeguards** against a class 3 energy source may be removed or defeated.
- A **skilled person** is presumed to use skill as a **safeguard** against a class 3 energy source

ASSET^{TM}

Applied Safety Science and Engineering Techniques

Taking Hazard Based Safety Engineering (HBSE) to the Next Level

ASSET™

Risk Management Systems

"**Absolute Safety** is only achievable at **Infinite Cost**"

- Jim Beyreis - Former VP @ UL

Driving a car (Voluntary risk)

- relatively high risk of injury due to accidents
- get to work to support our families
- Convenience
- recreation

Reduce the Risk (Can't eliminate it entirely!)

- air bags and antilock brakes
- reducing speed
- increasing following distance
- wearing seat belts.

ASSET™

Reliability Engineering

Reliability describes the ability of a system or component to function under stated conditions for a specified period of time

- Failure mode and effects analysis (FMEA)
- Fault tree analysis
- Root cause analysis
- Accelerated testing
- Thermal induced, shock and vibration fatigue analysis by FEA and / or measurement
- Avoidance of single point of failure
- Predictive and preventive maintenance: reliability centered maintenance (RCM) analysis
- Human error analysis

ASSET^{TM}

Functional Safety

- Functional safety is part of overall product safety which depends on the correct functioning of safety related control systems and software.
- Functional safety looks at what inputs go into a device and makes sure that the correct outputs come out of the device.
- If the product fails to generate the correct outputs, then there is a safety repercussion such as bodily harm.

ASSET™

Functional Safety

- It includes evaluations of:
  - Software
  - Hardware
  - Environmental Factors (e.g., electromagnetic compatibility, EMC)
  - Safety Lifecycle Management Processes

- IEC 61508, *Functional safety of electrical / electronic / programmable electronic safety-related systems - Part 2: Requirements for electrical / electronic / programmable electronic safety-related systems*

ASSET™

Human Factors

- Designing Systems, Products and Services to Make them Easier, Safer, and More Effective for Human Use
- Assess the fit between a person and the used technology
  - the job (activity) being done
  - demands on the user
  - equipment used (its size, shape, and how appropriate it is for the task)
  - information used (how it is presented, accessed, and changed)

ASSET™


1)
HAZARDOUS ENERGY SOURCE
+ Matter / Substance
2)
TRANSFER MECHANISM
3)
BODY PART
+ Property / Environment

FINAL EXAM

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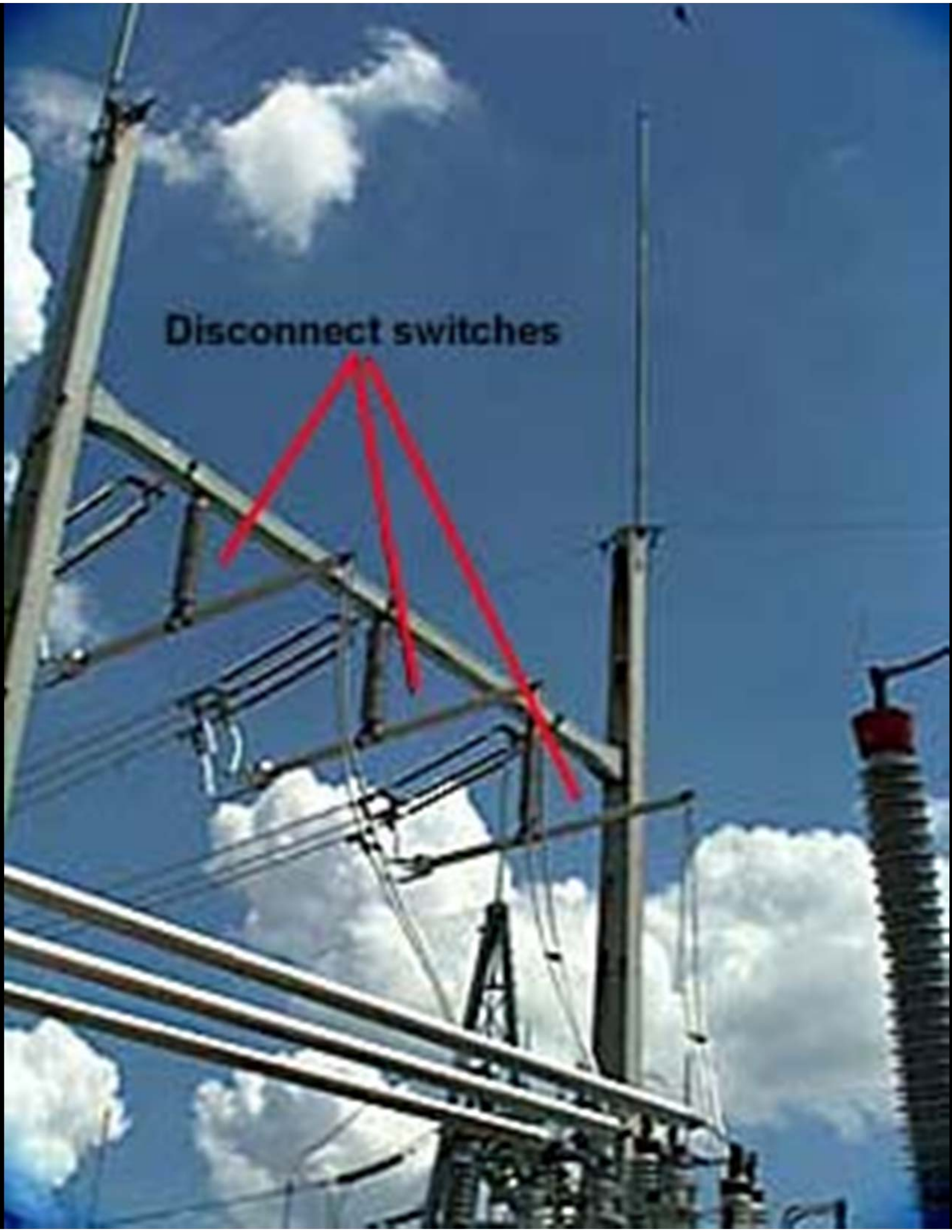
$\sqrt{-1}\ 2^3\ \Sigma\ \pi$

...and it was DELICIOUS!

i 2X2X2=8 sum pi


Disconnect switches

Lineman's Safety Equipment

QUESTIONS???