ELECTRICAL EQUIPMENT TASK BASED RISK ASSESSMENT – USING THE HAZARD RATING NUMBER (HRN) METHOD

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Risk – What is it?

- Probability of an event and its resulting consequence

- Risk = Likelihood x Consequence

- We all do "risky" activities each day

- We all manage "risk" each day

LOSS

SOMETHING BAD

UNCERTAINTY

DANGER

FATALITY

HAZARD

THREAT

INJURY

Background

- Several arc flash incidents at a site within a 24 month period
  - 480V switchgear arc flash – injury
  - 24kV switchgear arc flash – no injury
  - 24kV cable termination failure – no injury
  - 24kV transformer bushing failure – no injury
- Capital project initiated to improve reliability and safety
- Leadership challenge to spend capital on the "right" equipment
- Needed a method to quantify "risk"
- Prioritization

Machine Safety

- Origins date back to the Industrial Revolution
- New England states created legislation in the late 1800's
- Today OSHA 1910 Subpart O – minimum guarding requirements
- ANSI/B11 – Machine Safety – voluntary consensus standards
- ANSI/B11 "harmonized" with ISO 12100:2010
  - All starts with a machine "risk assessment"
  - Various "risk assessment" methods exist

Type A – Basic safety standards
Type B – Generic safety documents
Type C – Machine-specific safety standards

Basic Assessment Process

- Set boundaries
- Define tasks and identify the hazard
- Calculate risk
- Decide acceptable and unacceptable risk level
- Create mitigation plans for risk
- Implement and validate solutions
- Document result

In the machine safety world – lots of standards and guidance documents on machine guarding and protection

Can only protect a chainsaw so much for it to still perform its function. (OSHA 1910.266(e)(2) and ANSI/OPEI B175.1-2021)

HRN Method - C. Steel, 1990, "Risk Estimation", The Safety & Health Practitioner, June, pp. 20-21

- Reviewed by D. Coulson in 2014 – Concluded that many machine safety practitioners have been using the methodology since originally published in 1990

NUMBER OF PERSONS AT RISK (NP)

Value	Quantity
1	1-2 persons
2	3-7 persons
4	8-15 persons
8	16-50 persons
12	More than 50 persons

Example:
Four (4) people carpool to work. We want to calculate the HRN score for this activity.
NP=2

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FREQUENCY OF EXPOSURE (FE)

Value	Frequency
0.1	Infrequently
0.2	Annually
1	Monthly
1.5	Weekly
2.5	Daily
4	Hourly
5	Constantly

Example:
Four (4) people carpool to work. NP = 2
They do this five (5) days a week. FE = 2.5

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LIKELIHOOD OF OCCURRENCE (LO)

Value	Probability	Explanation
0.1	*Almost Impossible*	*Possible in extreme circumstances*
0.5	*Highly Unlikely*	*Though conceivable*
1	Unlikely	*But could occur*
2	Possible	But unusual
5	Even Chance	Could happen
8	Probable	Not surprised
10	Likely	Only to be expected
15	Certain	No doubt

Example:
NP = 2, FE = 2.5
Route is local state roads and interstate highways. Traffic is fairly heavy. Commute is a short distance. Car has latest safety features – auto pre-collision braking / warning, lane watch monitor, etc.   LO = 0.5 (of getting in an accident)

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DEGREE OF POSSIBLE HARM (DPH)

Value	Loss
15	Fatality
8	Loss of 2 limbs/eyes or serious illness (permanent)
4	Loss of 1 limb/eye or serious illness (temporary)
2	Break – major bone or minor illness (permanent)
1	Break – minor bone or minor illness (temporary)
0.5	Laceration / mild ill health effect
0.1	Scratch / bruise

=

Example:
NP = 2, FE = 2.5, LO = 2
Car has latest safety features – seat belts, air bags, crumple zones, pre-collision braking system, etc. DPH = 0.5

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0.1	Scratch / bruise

HAZARD RATING NUMBER (HRN)

HRN	Risk	Action Timetable
0-1	Acceptable risk	Accept risk / consider action
1-5	Very low risk	Action within 1 year
5-10	Low risk	Action within 3 months
10-50	Significant risk	Action within 1 month
50-100	High risk	Action within 1 week
100-500	Very high risk	Action within 1 day
500-1000	Extreme risk	Immediate action
Over 1000	Unacceptable risk	Stop the activity

HRN = NP x FE x LO x DPH
Example:
HRN = 2 X 2.5 X 2 X 0.5 = 5 (Low Risk)

Learnings from Machine Safety Assessments

- Risk assessments are subjective (LO and DPH)

- Need to be performed by knowledgeable teams

- Important to use the full range of factors

- Just because something bad hasn't happened doesn't mean it won't happen

- Determine acceptable level of risk (Common to strive to HRN=10 or less)

- Drive consistency in assessments

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- Risk assessments are subjective (LO and DPH)
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10-50	Significant risk	Action within 1 month
50-100	High risk	Action within 1 week
100-500	Very high risk	Action within 1 day
500-1000	Extreme risk	Immediate action
Over 1000	Unacceptable risk	Stop the activity

Example:
Four (4) people carpool to work. NP = 2
They do this five (5) days a week. FE = 2.5
Route is local state roads and interstate highways. Traffic is fairly heavy. Commute is a short distance. Car has latest safety features – auto pre-collision breaking / warning, lane watch monitor, etc. **Driver tends to exceed speed limit, does not use turn signals, and has accident history.**   LO = **8**
Because of the safety features. DPH = 0.5
HRN = 2 x 2.5 x **8** x 0.5 = **20 (Significant Risk)**
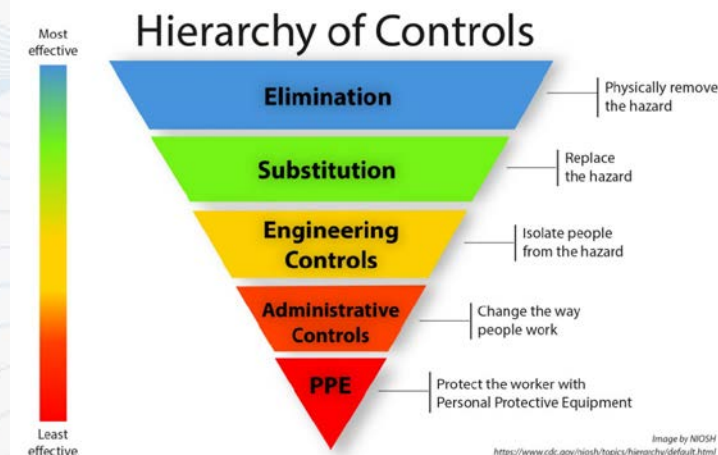
How applied to Electrical?

- Number of People (NP) – easy / straight forward

- Frequency of Exposure (FE) – durations are easy to define

- Likelihood of Occurrence (LO) – needs to be defined specifically for electrical equipment

- Degree of Possible Harm (DPH) – needs to be based on harm from electrical personnel

LO Guidance

- Machine safety guardians – developed a LO table to define the risk level based on the guarding level and the type of task

- For electrical – "LO" based on hierarchy of controls but adjusted for DIRECT or NO DIRECT interaction with power system components

HRN = NP x FE x LO x DPH

LIKELIHOOD OF OCCURRENCE GUIDANCE - ELECTRICAL				
Risk Level	No controls	15	15	N/A
	PPE / Admin -	15	10	5
	PPE / Admin +	10	8	2
	Active Engineering Controls	5	5	1
	Passive Engineering Controls	2	2	0.5
	Inherently Safe	0.5	0.5	0.1
	No access	0.1	0.1	0.1

	Common	Unusual	ECR / General Access
Common Task - More hazardous because it is "common" and person can get complacent.	Common	Unusual	ECR / General Access
Unusual Task - Less hazardous because the person concentrates more and does better job planning.	Direct exposure or interaction with power system parts	No direct exposure or interaction with power system parts	

Hierarchy of Controls

Most effective

Elimination — Physically remove the hazard

Substitution — Replace the hazard

Engineering Controls — Isolate people from the hazard

Administrative Controls — Change the way people work

PPE — Protect the worker with Personal Protective Equipment

Least effective

Image by NIOSH
https://www.cdc.gov/niosh/topics/hierarchy/default.html

DPH Guidance

- Machine safety guardians – developed a DPH table to define the injury level based on the energy level of the machine and the type of injury received

- For electrical – "DPH" based on arc flash incident energy and whether or not arc flash PPE is worn during tasks

$$HRN = NP \times FE \times LO \times DPH$$

DPH - ENERGY GUIDANCE					
Arc Flash Incident Energy		Incorrect or No PPE		Correct PPE	
		DPH	Injury Type	DPH	Injury Type
Energy Level	>60 cal/cm2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	8	1st and/or 2nd Degree Burns / Multiple Broken Bones / Puncture Wounds / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC
	> 40 cal/cm^2 to 60 cal/cm^2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	4	1st and/or 2nd Degree Burns / Multiple Broken Bones / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC
	>25 cal/cm^2 to <= 40 cal/cm^2	8	3rd Degree Burn / Broken Bones / Minor Puncture Wounds / Loss of Eye(s) / Permanent loss of hearing / MTC plus RWC or DAWC	2	1st and/or 2nd Degree Burns / Possible Broken Bones / Concussion / Hand or Foot Injury / Bruises / MTC plus RWC or DAWC
	>8 cal/cm^2 to <= 25cal/cm^2	2	3rd Degree Burn / Concussion / Bruises / Non-permanent loss of hearing / Recoverable eye injury / MTC or RWC	1	1st and/or 2nd Degree Burns / Concussion / Bruises / MTC or RWC
	>=1.2 cal/cm^2 to <=8 cal/cm^2	1	3rd Degree Burn / MTC or RWC	0.5	1st and/or 2nd Degree Burns / FAC
	<1.2 cal/cm^2	0.1	1st Degree Burn / FAC	0.1	N/A

Note: Not for shock assessment and voltage level / current level is not addressed.
FAC: First Aid Case   **MTC:** Medical Treatment Case
RWC: Restricted Day Case   **DAWC:** Days Away from Work Case

FE Guidance

- Guidance for selecting "FE" for the electrical task is also adjusted for whether or not the task involves DIRECT or NO DIRECT interaction with power system components.

- Purpose is to account for the decreased or increased hazard depending on interaction level with equipment.

FREQUENCY OF EXPOSURE (FE)

No Direct Exposure		Direct Exposure	
Value	Frequency	Value	Frequency
0.1	Monthly	1	Infrequently
0.2	Weekly	1.5	Annually
1	Daily	2.5	Monthly
1.5	Constantly	4	Weekly
		5	Daily

$$HRN = NP \times FE \times LO \times DPH$$

Application of the Electrical HRN Method

- Define the Evaluation Team
  - Electrical technology subject mater expert (as Facilitator)
  - Site electrical safety professional or EHS representative
  - Electrical technicians and operators
  - Plant leadership
- Define the Boundaries
  - Single piece of equipment, common pieces of equipment, group types of equipment together, voltage classes / levels
  - Up to the team to decide

- Define the Tasks
  - Identify all the tasks performed on the various pieces of equipment - Open/close breaker or switch, racking of breaker, IR inspections, AOV testing, ground set application, visual inspections, trouble shooting, traffic past equipment, etc.
- Identify Risks to Mitigate (i.e. HRN scores >10)
  - Identify mitigations or live with the risk
- Align Mitigations with Leadership
  - Decide what mitigations to implement
  - Decide residual risk

Electrical HRN Method Limitations

- Method is only safety based – reducing risk of an injury to people

- Equipment age and maintenance is not a significant factor

- The DPH is heavily driven by arc flash energy
  - Distance is "your friend" (i.e. greater distance = less arc flash energy)

- This is not a "reliability" tool

- Does not prevent electrical equipment failures

- Shock assessment and voltage/ampere levels not addressed
  - Shocks of =>50V can be lethal and remains as residual risk

Existing Plant Evaluation

10 Equipment Classes and 118 Tasks Evaluated with Site ESP and Plant HV Crew

24kV Switch yard / tower switches (SY=6)

24kV Junction Boxes (JB=6)

24kV Switchgear (MVS=10)

24kV GIS Switchgear (GIS=10)

24kV – 2400V or 480V Transformers (XFMR=12)

2400V or 480V Cable Bus / Bus Duct (BD=2)

2400V Switchgear (2400VSWGR = 8)

2400V Motor Control Center (2400VMCC=9)
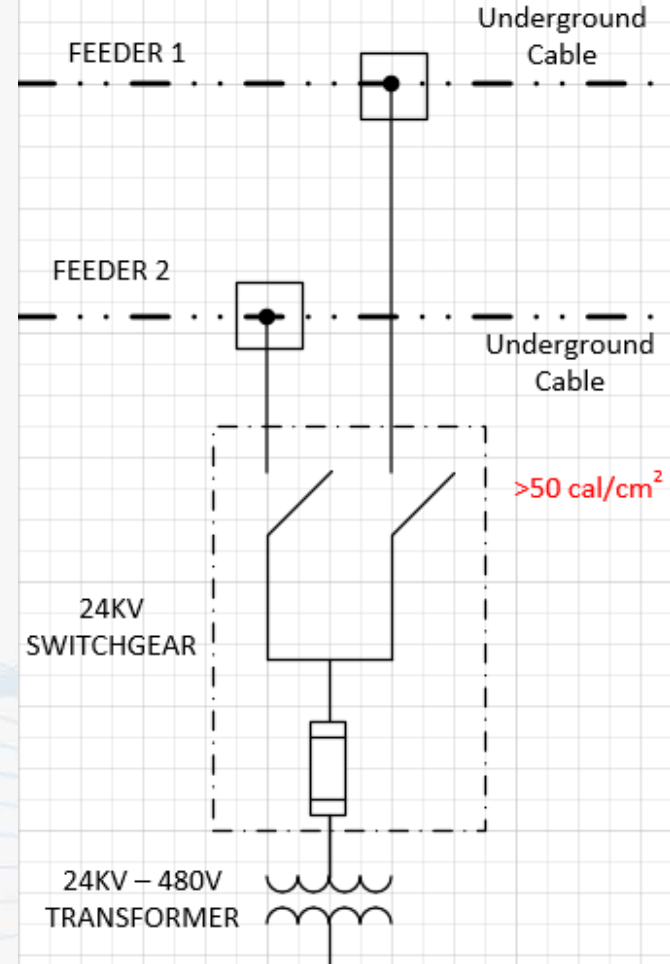
480V Switchgear (LVSGR=39)

480V Motor Control Centers (MCC=17)

NOT INCLUDED:
Small transformers, lighting panels, power panels, instrument panels, heat trace panels, vendor packaged equipment, field disconnects (i.e. equipment fed by 480V MCCs)

24kV Switchgear (15 Sets) - Tasks

- Manual operation of switch (On and Off)
- Infrared inspection
- Absence of voltage testing (AOV)
- Application of ground sets
- Visual inspection
- Walking past equipment

- Some may have different tasks or exposures may be different

Worked Examples

- Operation of 24kV switchgear disconnect

- Paper has a worked example for a 24kV junction box task

- Paper has a partially worked example for a 480V switchgear task

Example – Operation of 24kV Manual Switch

Item No.	Substation	Equipment Type	Task Description	Task Freqency	PPE Yes No	Exposure to equipment or interaction with power system parts Direct None	Manufacturer / Age / Condition of Equipment / Procedures / Operation	Arc Flash Hazard at the Person >60 cal/cm^2 >40 cal/cm^2 - 60 cal/cm^2 >25 cal/cm^2 - 40 cal/cm^2 >8 cal/cm^2 - 25 cal/cm^2 >=1.2 cal/cm^2 - 8 cal/cm^2 <1.2 cal/cm^2
Item No	**Substation or Equip Group**	**Equipment Type**	**Task Description**	**Task Frequency**	**PPE Required**	**Exposure**	**Manufacture / Age / Condition / Procedure / Operation**	**Incident Energy Level**
MVS1	All	24kV metal enclosed switchgear with two (2) switches and fuse to transformer	Manual operation of switch handle (On or Off) by operator local to equipment	Assuming 6 events per year there we need to switch between feeders: 16 substation to be switched between feeders. To do this for 6 events per year about 560 switch operations need to occur.	YES	DIRECT	Vendor A and Vendor B, most are 1960's and 1970s, SUB1 and SUB2 are from 2000s, SUB3 is new in 2021, all equipment has been maintained within the last 5 years, good procedures and training, some close to road ways and foot traffic, and some have an elevated concrete pad with bollards on it in front of equipment. SUB4 roof was replaced in 2023.	>40 cal/cmcm - 60 cal/cmcm

Example – Operation of 24kV Manual Switch

- For this task, there are two (2) electricians involved so, NP = 1

Number of Persons	Frequency of Exposure		Likelihood of Occurrence (See Electrical Likelihood of Occurrence Guidance Tab)	Degree of Possible Harm (See Electrical Degree Of Possible Harm Guidance Tab)	HRN Risk Score
	NO DIRECT	DIRECT			Negligible - 0 to 1
1 = 1-2 Persons	0.1=Monthly	N/A	0.1=Almost Impossible	0.1=Scratch or Bruise	Very Low - >1 to 5
2 = 3-7 Persons	0.2=Weekly	N/A	0.5=Highly Unlikely	0.5=Laceration	Low - >5 to 10
4 = 8-15 persons	1=Daily	1=Infrequently	1=Unlikely but could occur	1=Break Minor Bone (TEMPORARY)	Significant - >10 to 50
8 = 16-50 Persons	1.5=Constantly	1.5=Annually	2=Possible but unusual	2=Break Major Bone	High - >50 to 100
12 = 51 or more Persons	N/A	2.5=Monthly	5=Even Chance, could happen	4=Loss of 1 Limb or eye	Very High - >100 to 500
	N/A	4=Weekly	8=Probable, not surprised	8=Loss of 2 Limbs or eyes	Extreme - >500 to 1000
	N/A	5=Daily	10=Likely, Only to be expected	15=Fatality	Unacceptable - >1000
			15=Certain, no doubt		

Number of People	Freq of Exposure	LO	DPH	HRN Risk Score
1				0

Example – Operation of 24kV Manual Switch

- Due to the system configuration, to move the plant from dual feeder to single feeder operation there are a lot of switching events

- Evaluation team came up with 560 switch operations per year and this is DIRECT interaction with power system components so, FE = 5

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Number of People	Freq of Exposure	LO	DPH	HRN Risk Score
1	5			0

Example – Operation of 24kV Manual Switch

- Correct PPE, hazard warning signs, written procedures, adequate training, equipment > 5 years old but maintained, no known operating issues, common task
- This leads us to PPE / Admin + so, LO = 10

LIKELIHOOD OF OCCURRENCE GUIDANCE - ELECTRICAL

Risk Level				
	No controls	15	15	N/A
	PPE / Admin -	15	10	5
	PPE / Admin +	10	8	2
	Active Engineering Controls	5	5	1
	Passive Engineering Controls	2	2	0.5
	Inherently Safe	0.5	0.5	0.1
	No access	0.1	0.1	0.1

	Common	Unusual	ECR / General Access
Common Task - More hazardous because it is "common" and person can get complacent.	Common	Unusual	ECR / General Access
Unusual Task - Less hazardous because the person concentrates more and does better job planning.	Direct exposure or interaction with power system parts	No direct exposure or interaction with power system parts

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Number of People	Freq of Exposure	LO	DPH	HRN Risk Score
1	5	10		0

Example – Operation of 24kV Manual Switch

- Correct PPE for task and arc flash >40 cal/cm^2 – 60 cal/cm^2 so, DPH = 4

DPH - ENERGY GUIDANCE

Arc Flash Incident Energy		Incorrect or No PPE		Correct PPE	
	DPH	Injury Type	DPH	Injury Type	
>60 cal/cm2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	8	1st and/or 2nd Degree Burns / Multiple Broken Bones / Puncture Wounds / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC	
> 40 cal/cm^2 to 60 cal/cm^2	15	3rd Degree Burn / Multiple Broken Bones / Puncture Wounds / Hospitalization / DAWC / Fatality	4	1st and/or 2nd Degree Burns / Multiple Broken Bones / Bruises Hospitalization / Posttraumatic Stress Disorder / DAWC	
>25 cal/cm^2 to <= 40 cal/cm^2	8	3rd Degree Burn / Broken Bones / Minor Puncture Wounds / Loss of Eye(s) / Permanent loss of hearing / MTC plus RWC or DAWC	2	1st and/or 2nd Degree Burns / Possible Broken Bones / Concussion / Hand or Foot Injury / Bruises / MTC plus RWC or DAWC	

Energy Level

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Number of People	Freq of Exposure	LO	DPH	HRN Risk Score
1	5	10	4	200

HRN = 1 x 5 x 10 x 4 = 200 (VERY HIGH RISK)

Example – Operation of 24kV Manual Switch

- HRN = 200 (Very high risk)

- Goal is HRN 10 or less
  - Goal chosen by assessment team

- Need to take action to address the risk

- Brainstorm about possible mitigations and recalculate HRN

- Mitigations:
  - MT-7: Use "other" method to determine more realistic arc flash energy
  - MT-15: Create shorter clearing time by adding device between utility / owner interface (i.e. recloser on 24kV feeders) changing clearing time from 1.5 seconds to 0.5 seconds
  - MT-10: Install fixed mounted remote operators to get operator out of arc flash boundary
  - MT-19: Remove existing manual switches and change to motor operated switches to get operator out of arc flash boundary

Example – Mitigations

			Arc Flash Hazard at the Person	Number of Persons	Frequency of Exposure	Likelihood of Occurrence	Degree of Possible Harm	HRN Risk Score	
Item No.	**PPE** Yes No	**Exposure to equipment or interaction with power system parts** Direct None	>60 cal/cm² >40 cal/cm² - 60 cal/cm² >25 cal/cm² - 40 cal/cm² >8 cal/cm² - 25 cal/cm² >=1.2 cal/cm² - 8 cal/cm² <1.2 cal/cm²	1 = 1-2 Persons 2 = 3-7 Persons 4 = 8-15 persons 8 = 16-50 Persons 12 = 51 or more Persons	**NO DIRECT** 0.1=Monthly 0.2=Weekly 1=Daily 1.5=Constantly N/A N/A N/A **DIRECT** N/A N/A 1=Infrequently 1.5=Annually 2.5=Monthly 4=Weekly 5=Daily	**(See Electrical Likelihood of Occurrence Guidance Tab)** 0.1=Almost Impossible 0.5=Highly Unlikely 1=Unlikely but could occur 2=Possible but unusual 5=Even Chance, could happen 8=Probable, not surprised 10=Likely, Only to be expected 15=Certain, no doubt	**(See Electrical Degree Of Possible Harm Guidance Tab)** 0.1=Scratch or Bruise 0.5=Laceration 1=Break Minor Bone (TEMPORARY) 2=Break Major Bone 4=Loss of 1 Limb or eye 8=Loss of 2 Limbs or eyes 15=Fatality	Negligible - 0 to 1 Very Low - >1 to 5 Low - >5 to 10 Significant - >10 to 50 High - >50 to 100 Very High - >100 to 500 Extreme - >500 to 1000 Unacceptable - >1000	**Mitigation Options - Notes, follow up items, mitigation**
Item No	PPE Required	Exposure	Incident Energy Level	Number of People	Freq of Exposure	LO	DPH	HRN Risk Score	Mitigation
MVS1	YES	DIRECT	>40 cal/cmcm - 60 cal/cmcm	1	5	10	4	200	Original
MVS1-MT7	YES	DIRECT	>25 cal/cmcm - 40 cal/cmcm	1	5	10	2	100	Use Method to Calculate Arc Flash Energy
MVS1-MT15	YES	DIRECT	>=1.2 cal/cmcm - 8 cal/cmcm	1	5	2	0.5	5	Recloser
MVS1-MT10	YES	DIRECT	<1.2 cal/cmcm	1	5	2	0.1	1	Remote Operators
MVS1-MT19	YES	DIRECT	<1.2 cal/cmcm	1	5	2	0.1	1	Motor Operator

Passive engineering controls and lower arc flash incident energy reduces the risk of injury.

Summary

- Determining risk is subjective but with guidance, subjectivity can be reduced.

- The HRN method and how LO and DPH have been defined for electrical tasks allows "risk" to be calculated to identify electrical safety improvement opportunities.

- Okay to not drive to HRN 10 or less, the concept is that you do something to lower risk – residual risk is okay.

Thank you

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