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Evaluation and Implementation of Safety Protocols for 600W Solar Panel Installation on University Buildings

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Abstract: The increasing adoption of renewable energy in universities presents opportunities for sustainable power generation but also introduces significant safety challenges, particularly during rooftop solar panel installations. Improper handling of structural and electrical requirements can result in falls, electrocution, fire hazards, and long-term operational risks. This study evaluates safety protocols for the installation of a 600W solar panel system on a university building. A Job Safety Analysis (JSA) was used to identify hazards across installation tasks, while a risk matrix ranked hazards by severity and likelihood. To strengthen safety implementation, a Safety Protocol Implementation Equation—Safety = Awareness × Preparation × Action—was developed, incorporating weighted factors such as training, equipment quality, compliance, and proactive reporting. A Job Safety Analysis (JSA) identified hazards such as falls, shocks, fire, and weather risks, recommending preventive measures like PPE, scaffolding, and proper wiring. A risk matrix was applied to rank hazards by severity and likelihood, prioritizing immediate controls for high-risk tasks. To systematize safety, a Safety Protocol Implementation Equation was developed: Safety = Awareness × Preparation × Action. Weighted factors, including training, equipment quality, compliance, and reporting, generate a measurable Safety Score, guiding effective, regulation-compliant solar installation.

Keyword: Solar Installation, Safety Protocols, Risk Assessment, Job Safety Analysis, University Buildings.

INTRODUCTION

The global pursuit of environmentally friendly energy solutions has significantly accelerated the transition towards green energy, with institutions such as universities taking a central role in this transformation. The pressing need to reduce reliance on fossil fuels, minimize greenhouse gas emissions, and adopt renewable alternatives has positioned solar power as a critical option for sustainable electricity generation. Solar energy stands out for being abundant, renewable, and clean, thus aligning with worldwide strategies for climate change mitigation (Kishore et al, 2025; Owusu & Asumadu-Sarkodie, 2016). Lord et al, (2021) emphasizes this potential by noting that the sun provides more energy to the earth in one hour than the world consumes in a year, underscoring its vast untapped capacity to meet human energy demands.

In the Nigerian context, unreliable electricity supply remains a persistent barrier to socioeconomic and institutional development. Universities, as centers of research and academic excellence, have not been spared from the detrimental effects of erratic grid power. At Nnamdi Azikiwe University, inconsistent power supply has disrupted academic schedules, administrative operations, and essential services, compelling reliance on fuel-powered generators that are both costly and environmentally unsustainable (Feron, 2016). This energy insecurity highlights the urgent need to adopt renewable energy systems that not only ensure reliability but also support institutional resilience.

Solar power installations on university campuses offer a viable contingency measure, providing stable electricity for academic and administrative functions. Studies reveal that renewable energy projects in higher education settings contribute significantly to operational continuity, reduced carbon footprints, and institutional energy independence (Wang & Zhao, 2023). A 600W solar panel system, though modest, represents an essential step toward addressing Nnamdi Azikiwe University's energy challenges by enhancing efficiency, reducing dependence on fossil fuels, and contributing to broader sustainability goals.

However, while the adoption of solar systems provides environmental and operational benefits, it also introduces substantial occupational and technical risks, particularly when installed on rooftops. Research indicates that improper handling of photovoltaic (PV) systems can expose workers and end-users to hazards such as falls, electrocution, fire outbreaks, and equipment failure (Kulor et al, 2024). These dangers highlight the importance of instituting robust safety measures during planning, installation, and maintenance phases of solar energy systems. In school environments where students, staff, and contractors interact daily, potential risks are heightened, necessitating strict adherence to health and safety protocols. The presence of multiple stakeholders makes it imperative to implement structured measures that safeguard lives and institutional resources.

Recent studies emphasize that without clear and enforceable safety frameworks, schools remain vulnerable to accidents and disruptions, particularly when integrating infrastructure projects such as renewable energy systems (Osegbue, Ohamobi, & Alordiah, 2025). This finding agrees with Ohamobi and Ezeaku (2016), who stressed that student engagement and academic achievement are closely linked to the presence of safe and supportive learning conditions. In a related study, Onyekazi et al. (2024) noted that effective management strategies within schools not only improve staff performance but also reinforce compliance with organizational standards, including safety regulations. Thus, structured safety management practices are indispensable when deploying solar installations in institutional contexts. According to Kruzhilko et al, (2020), effective occupational risk management requires a holistic approach that includes hazard identification, the use of personal protective equipment (PPE), adherence to electrical safety standards, and provision of training to personnel. Without these precautions, the likelihood of accidents, injuries, or fatalities significantly increases.

Furthermore, compliance with international and local regulations enhances both safety and system reliability. The International Labour Organization (ILO, 2019) stresses the importance of regulatory frameworks in ensuring safe working conditions, particularly in high-risk sectors such as construction and energy installation. The adoption of renewable energy in universities is both an environmental necessity and an operational priority, yet safety concerns during solar panel installation remain underexplored. While numerous studies emphasize the environmental and economic benefits of solar power (Owusu & Asumadu-

Sarkodie, 2016), limited attention has been given to the occupational risks associated with rooftop photovoltaic (PV) system integration in institutional settings. Existing research often prioritizes system performance and cost efficiency (Alanazi, 2023; Anderson & Rex, 2023), leaving a gap in literature on structured safety protocols tailored to campus environments.

At Nnamdi Azikiwe University, frequent grid failures disrupt academic and administrative processes, making solar energy adoption essential. However, improper installations could expose workers and students to hazards such as falls, electrocution, and fire outbreaks (Kulor et al, 2024). Although international frameworks stress occupational safety (ILO, 2019), their direct application to Nigerian universities is limited, creating a contextual gap. Moreover, few studies provide measurable models that integrate awareness, preparation, and compliance into a unified safety framework. Therefore, this study is justified in addressing these gaps by evaluating and implementing comprehensive safety protocols for 600W solar panel installation, ensuring both energy reliability and occupational safety in university settings.

METHOD

The methodology outlines steps for identifying, classifying, and applying safety protocols during the installation of 600W solar panels on the university building. The methodology is designed to provide a structured approach to evaluating safety measures from engineering and practical perspectives. This study regards pre-installation as one phase and installation as the other phase for safety measures. Different measures are taken to ensure workers, equipment, and the site are appropriately secured throughout the installation.

Structural Safety Protocols: Safety Concerns During Panel Installation

Solar panels fitted on universities' rooftops must meet tough health and safety standards at all times, because of their potential risks. Therefore, this study points out significant safety challenges and explains what actions need to be taken to ensure both the safety of personnel and the safety of equipment and buildings. Then, there are specific steps to safety that must take place during the rooftop installation.

a. **Structural Analysis of the Roof/Surface:** First, a complete check of the building's rooftop/surface structure before installation. This check is done to confirm that the surface can safely carry the 600W solar panels, frames, and all the other installed equipment. The inspection should cover any cracks, possible material fatigue, and weaknesses.

b. **Installation of Industrial Scaffolding:** Industrial scaffolding is installed around the building to facilitate safe access to elevated work areas. This scaffolding serves as a secure platform for workers during installation and maintenance. It reduces the risk of falls and provides stable footing while carrying tools or panels.

c. **Introduction of Anchor Points on the Roof:** Anchor points are installed as fixed safety mechanisms that allow workers to attach their safety harnesses while working at height. These points must be strategically placed based on the layout of the rooftop and the expected movement of personnel. Properly installed and certified anchor points significantly reduce the risk of falls and are a critical component of any fall arrest system.

d. **Installation of Harness Line for Installers:** A harness line system (lifeline) is installed to provide continuous fall protection for workers. This system ensures that installers remain tethered at all times while on the roof, allowing for mobility without sacrificing safety. Horizontal and vertical lifelines are used depending on the roof structure and must be regularly tensioned correctly and inspected. This measure is significant during panel alignment and wiring when workers are often required to move along narrow roof sections.

e. **Use of Full Personal Protective Equipment (PPE):** All personnel involved in the installation must wear complete Personal Protective Equipment (PPE) to protect against electrical, physical, and environmental hazards. Standard PPE includes helmets, insulated gloves, safety harnesses, steel-toe boots, and high-visibility vests. Additional PPE, such as anti-slip shoes and UV-resistant clothing, is recommended for rooftop work due to exposure to height and weather conditions.

f. **Installation of Non-Slip Walk Paths:** Non-slip textures are added to the roof so that people can safely move around on the roof. They allow contractors and engineers to safely move around on the roof and when making later changes.

Electrical Safety Protocols: Safety Concerns During Panel and Inverter Installation

Solar energy system installation should always focus on electrical safety. Mishandling during the connection and activation processes can cause damage to equipment, make the system unsafe with fire hazards, result in electric shocks, and cause the system to work poorly. The following rules are strictly applied during the installation of the panel and inverter to prevent such accidents from happening.

a. **Confirm the DC Operating Voltage of the Inverter System:** Before any panel-string configuration is made, it is crucial to confirm the DC operating voltage range of the inverter. This ensures that the solar panel configuration matches the voltage input limits of the inverter. Over-voltage can damage internal components, while under-voltage may prevent the system from operating optimally. The inverter's datasheet should guide the maximum input voltage, operating MPPT voltage range, and startup voltage. This step directly influences how many solar panels are connected in series and affects safety and performance.

b. **Size the Electrical Cable Appropriately for the Solar Panel String:** The cable size used for solar panel strings must be selected based on the expected current flow and the distance between the panels and the inverter. Undersized cables may overheat and pose fire risks, while oversized cables may be unnecessarily expensive and more complex to install. Proper cable sizing helps minimize voltage drop and ensures efficient power transmission. Compliance with electrical codes (such as NEC 690) ensures these selections are safe and durable.

c. **Use the Correct MC4 Connectors for Panel Connections:** All panel-to-panel and string-to-combiner box connections should be made using genuine, compatible MC4 connectors. MC4 connectors are designed for outdoor photovoltaic systems and provide weatherproof, secure locking mechanisms. Using incorrect or mismatched connectors can result in loose connections, increased resistance, arcing, or even system failure. Installers must ensure all connectors are fully locked and that male and female ends match according to manufacturer specifications.

d. **Use Appropriate Cable Size for Inverter Connections:** Like string cabling, the DC and AC cables connecting the inverter to the combiner box and the distribution board must be rated appropriately. The cable must handle the maximum expected current from the panel array for the DC side, and it must accommodate the inverter's rated output for the AC side. Consideration must also be given to insulation type, temperature ratings, and installation environments (e.g., UV exposure or conduit installation).

e. **Use the Right Torque for Mechanical Connectors (Bolts and Nuts):** All mechanical joints, especially of the terminal lugs, circuit breakers, and grounding points, should be tightened as indicated by the manufacturer. Tightening screws too much could ruin threads, and failing to tighten enough can make wires contact, causing the heating of wire or an electrical spark. Use a calibrated torque wrench to ensure you have the proper pressure.

f. **Confirm All Connections Before System Energizing:** Every electrical connection must be checked carefully before the power is turned on. One should check polarity, verify the values of the torque, check for continuity, measure insulation resistance, and spot any loose or exposed wires. Taking this measure helps to avoid dangers such as short circuits, reversed connections, and ground faults during installation.

Risk Management and Assessment

a. Hazard Identification in Solar Installation Projects

Hazard identification is the first and most critical step in mitigating risks during solar panel installation. A thorough assessment of potential risks associated with rooftop and electrical tasks helps ensure a safe work environment for all personnel involved.

Common Hazards Identified:

- **Electrical Hazards**: Risks from exposed wires, arc flashes, high DC voltages, and improper grounding.
- **Fall Hazards**: Elevated rooftops pose fall risks if harnesses, scaffolding, and anchor points are not correctly used.
- **Fire Risks**: Poor cable sizing, loose connections, or substandard components may cause overheating and fire outbreaks.
- **Manual Handling Injuries**: Lifting and maneuvering heavy panels or inverters without proper support or techniques.
- **Weather-Related Risks**: Wet or windy conditions increase the chances of slipping, electrical hazards, and delayed work.

b. Job Safety Analysis (JSA)

A Job Safety Analysis breaks down the installation process into specific tasks, identifies potential hazards in each task, and recommends safety measures to mitigate those hazards.

Table 3.1 Job Safety Analysis Table

Task	Potential Hazard	Risk	Preventive Measures
Site inspection and roof access	Fall from height, unstable roof	High	Use scaffolding, PPE, and safety harnesses; conduct structural assessment of roof
Lifting and moving solar panels	Muscle strain, slips, falling objects	Medium	Use team lifting, proper lifting techniques, wear gloves and safety boots
Panel installation	Electrical shock, falling from roof	High	De-energize circuits, install anchor points, wear harnesses and non-slip shoes
Cable and inverter connection	Arc flash, incorrect wiring, shock	High	Verify voltage ratings, use insulated tools, follow electrical safety protocols
System energizing	Overvoltage, improper sequence	High	Follow OEM instructions, double-check all connections, use PPE and fire extinguisher nearby

Adverse weather response	Slips, tool mishandling, wind hazards	Medium	Postpone work during rain or high winds; ensure tools and materials are secured

Risk Matrix Application

A risk matrix evaluates the likelihood and severity of each hazard to prioritize mitigation efforts. Below is the 5x5 risk matrix applied to key hazards during solar installation:

a. Risk Matrix Key

Severity: How bad is the outcome
1: Negligible
2: Minor
3: Moderate
4: Major
5: Catastrophic

Table 3.2 Severity table

score	Severity Level	Meaning
1	Negligible	Little or no injury; no damage
2	Minor	Minor injury or damage; first aid needed
3	Moderate	Injury or damage requiring medical treatment or repair
4	Major	Serious injury or major damage; could stop work temporarily
5	Catastrophic	Fatality or permanent disability; significant property loss

b. Likelihood: (How likely is it to happen)
1: Rare
2: Unlikely
3: Possible
4: Likely
5: Almost Certain

Table 3.3 Likelihood table

score	Likelihood Level	Meaning
1	Rare	Very unlikely to occur; may happen once in 10+ years
2	Unlikely	Not expected to happen regularly
3	Possible	Could happen occasionally
4	Likely	Expected to happen often

5	Almost Certain	Expected to happen regularly or very soon

Risk Rating (Severity × Likelihood)

You multiply the severity score by the likelihood score to get the risk rating. This rating tells you how serious a hazard is overall:

Table 3.3 Risk Rating Table

Risk Rating (S × L)	Risk Level	Action Required
1–5	Low	Acceptable; monitor
6–10	Moderate	Minimize if possible; monitor regularly
11–15	High	Immediate control needed; assign safety measures
16–25	Critical	Stop work until risk is reduced; strict control required

Risk Matrix Analysis

Table 3.4 Risk Matrix Analysis table

Hazard	Severity	Likelihood	Risk Rating	Action Required
A fall from a rooftop	5 (Catastrophic)	3 (Possible)	15 (High)	Use fall protection systems and anchor lines
Electrical shock (DC/AC)	4 (Major)	4 (Likely)	16 (High)	Insulate tools, check polarity, and de-energize before work
Arc flash from connections	4 (Major)	3 (Possible)	12 (High)	Use PPE, follow the correct connection sequence
Improper lifting injuries	2 (Minor)	3 (Possible)	6 (Moderate)	Training on lifting techniques, team lifting
Fire due to poor wiring	4 (Major)	2 (Unlikely)	8 (Moderate)	Use certified components, and torque connections
Weather-related slips/falls	3 (Moderate)	3 (Possible)	9 (Moderate)	Monitor weather, suspend work in unsafe conditions

Developing an Equation for the Implementation of the Safety Protocol and Weight Assignment

a. Developing an Equation for the Implementation of the Safety Protocol

a) Conceptual Formula

At the heart of every safe workplace lies a simple but powerful principle:

Safety = Awareness × Preparation × Action.

This Safety Equation isn't just a catchy formula; it's a reminder that true safety is achieved when all three critical elements work together. (https://ohse.ca/safety-equation/)

We treat each component as a factor contributing to safety, where:

- **Awareness (A):** Knowledge of potential hazards, risk perception, safety training, etc.
- **Preparation (P):** Availability of safety equipment, protocols, checklists, and emergency plans.
- **Action (Ac):** Actual safe behaviors, following procedures, using PPE, reporting issues, etc.

  Safety Score (S)= A× P× Ac (3.1)

  Where:

  - SS = Overall Safety Score (0–1 or 0–100)
  - A = Awareness factor
  - P = Preparation factor
  - Ac = Action factor

  The above equation shows that if any one of the components is zero, then safety fails, which is realistic.
- Awareness Factor $(A) = W_1(T) + W_2(E)$ (3.2)

  Where;

  T = Training Level

  E = Experience or Education
- Preparation (P) $= W_3(Q) + W_4(R)$ (3.3)

  Where;

  Q = quality of tools and safety equipment

  R = Risk Planning and Documentation
- Action (Ac) = $W_5(C) + W_6(F)$ (3.4)

  Where;

  C = Compliance rate (PPE usage)

  F = Frequency of proactive action (Safety Reporting)

  $W_1 + W_2 + W_3 + W_4 + W_5 + W_6 = 1$ (3.5)

b) Safety Protocol Formula:

S = $[W_1(T) + W_2(E)] \times [W_3(Q) + W_4(R)] \times [W_5(C) + W_6(F)]$ (3.6)

S$\in [0,1]\ or\ [0,100]$

N/B: score will be a number between 0 and 10, where closer to 10 = higher safety.

[T, E, Q, R, C, and F] are rated from 0 to 1, based on observation or scoring

b. Weight Assignment

Weight refers to the importance or influence of each safety factor in contributing to the overall safety score

$W_1 - W_6$ are Weights

In the formula, weights $W_1 - W_6$ represent the relative importance of each sub-factor in contributing to overall safety. They allow prioritizing certain variables over others based on how critical they are in your specific context

Table 3.5 Weight Assignment Table

Factor	Sub-Factor	Weight
Awareness	Safety Training (T)	0.6
	Field Experience (E)	0.4
Preparation	quality of tools and safety equipment (Q)	0.7
	Protocol Documentation (R)	0.3
Action	Rule Compliance (C)	0.8
	Proactive Reporting (F)	0.2

RESULT AND DISCUSSION

Explanation on the Job Safety Analysis (JSA)

A Job Safety Analysis (JSA) is a step-by-step way of looking at a job to spot what could go wrong and figure out how to prevent it. Think of it like planning a trip before you leave; you check the weather, the fuel in your car, and the route, so you're ready for anything. For installing solar panels, the JSA breaks the whole job into smaller tasks, then for each one:

1. Identifies possible hazards (things that could hurt people or cause damage).
2. Assesses the level of risk (how bad it could be and how likely it is to happen).
3. Safety measures should be recommended to avoid or reduce the danger.

For example:

- **Site inspection and roof access**: You could fall or find the roof weak. The solution is to wear safety harnesses, use scaffolding, and ensure the roof can handle your weight before stepping on it.
- **Lifting solar panels:** You could strain your back or drop a panel. Work in teams, lift correctly, and wear gloves and strong boots.
- **Panel installation:** You could get shocked or fall. Keep electrical circuits off, secure yourself with a harness, and wear non-slip shoes.
- **Cable and inverter connection:** Risk of electrical arc flashes and shocks. Use insulated tools, check voltages, and follow wiring safety rules.
- **System energizing:** If done in the wrong order, it could cause overvoltage or damage. Double-check connections and follow the manufacturer's instructions, using PPE and a fire extinguisher nearby.
- **Adverse weather:** Rain or wind can cause slips and accidents. Pause work until the weather improves and secure tools and materials.

The JSA ensures that hazards are spotted before they become accidents so that everyone can work safely and efficiently.

Explanation on the Risk Matrix Application

When hazards are identified, we need a way to rank them to know which ones need urgent attention. That's where a risk matrix comes in.

The risk matrix looks at two things:

a. **Severity:** How bad could it be if the hazard happens?

b. **Likelihood:** How often or how likely is it to happen?

a. Severity Scale (1–5)
   1: Negligible: No real injury or damage.
   2: Minor: Small injury, maybe a first-aid bandage.
   3: Moderate: You might need medical treatment or repairs.
   4: Major: Serious injury or damage that could stop work.
   5: Catastrophic: Could cause death, permanent disability, or huge property loss.
b. Likelihood Scale (1–5)
   1: Rare – Might happen once in ten years.
   2: Unlikely – Could happen, but not often.
   3: Possible – Might happen occasionally.
   4: Likely – Probably will happen often.
   5: Almost Certain – Expected to happen very soon or regularly.

Explanation of the Safety Protocol Implementation Equation

A Safety Equation was developed to guide the implementation of a robust safety protocol for the solar system installation based on the principle that safety is the product of awareness, preparation, and action (OHSE, n.d.). This approach transforms the concept of workplace safety into a measurable, structured model that can be applied during project execution.

The equation is expressed as:

$$S = [W_1(T) + W_2(E)] \times [W_3(Q) + W_4(R)] \times [W_5(C) + W_6(F)] \quad (4.1)$$

- **S** = Overall Safety Score (ranging from 0 to 1 or scaled to 0–100)
- **T** = Training Level (extent of formal safety instruction received)
- **E** = Field Experience or Safety-Related Education
- **Q** = Quality of Tools and Safety Equipment
- **R** = Risk Planning and Documentation Quality
- **C** = Compliance Rate with Rules and PPE Usage
- **F** = Frequency of Proactive Safety Actions (e.g., hazard reporting)

The design of this equation reflects the realistic notion that if any of the three significant safety components awareness, preparation, or action is missing (i.e., a score of zero), overall safety is compromised regardless of performance in the other areas.

To adapt the equation to the project's specific conditions, weights (W_1–W_6) were introduced. These weights represent the relative importance of each sub-factor within the three main components. For instance, safety training ($W_1 = 0.6$) was given slightly more importance than field experience ($W_2 = 0.4$) because structured, standardized training is seen as more universally applicable than individual experience, which can vary greatly.

Similarly, the preparation component prioritizes the quality of tools and safety equipment ($W_3 = 0.7$) over protocol documentation ($W_4 = 0.3$), as reliable equipment has a more immediate impact on preventing incidents. Within the action category, rule compliance ($W_5 = 0.8$) is emphasized over proactive reporting ($W_6 = 0.2$), recognizing that following established safety rules consistently has the most direct effect on avoiding accidents.

When field values for T, E, Q, R, C, and F are scored between 0 (poor) and 1 (excellent) based on observations during site inspection, they can be plugged into the equation to calculate the Safety Score. This score serves as a practical, numerical representation of the readiness and effectiveness of safety protocol implementation, helping project managers identify areas for improvement before proceeding with high-risk installation tasks.

Job Safety Analysis (JSA), the risk matrix, and the Safety Protocol Implementation Equation represent complementary frameworks for ensuring safe solar panel installation. JSA systematically decomposes tasks to identify hazards, assess risks, and recommend preventive measures. In contrast, a risk matrix quantifies these risks by evaluating severity and likelihood, enabling prioritization of hazards that demand urgent intervention. In a related study, Kulor et al. (2024) demonstrated that combining JSA with risk matrix applications reduced workplace incidents in construction projects, supporting the effectiveness of integrating qualitative and quantitative assessments.

This finding agreed with research by Brown (2023), who emphasized that risk matrices enhance JSA by providing numerical clarity, especially when assessing high-risk activities like rooftop work and electrical connections. However, unlike traditional approaches, the Safety Protocol Implementation Equation advances safety management by translating awareness, preparation, and action into a measurable score. In contrast, a study by Ozobu et al. (2023) found that safety culture in Nigerian universities often lacks structured metrics, resulting in inconsistent compliance with occupational safety rules.

CONCLUSION

This study examined the implementation of safety protocols necessary for successfully integrating a solar power system, focusing on minimizing occupational hazards during the installation process. An on-site inspection was conducted to identify potential safety concerns, evaluate site-specific risks, and determine appropriate preventive measures. Using a Job Safety Analysis (JSA) and a risk assessment matrix, hazards were systematically classified and control measures prioritized to ensure compliance with safety standards and regulatory requirements.

A key contribution of this study was the derivation of a Safety Implementation Equation, Safety = Awareness × Preparation × Action, which integrates weighted parameters representing training, planning, hazard identification, personal protective equipment (PPE) usage, emergency readiness, and procedural compliance. This equation is a quantitative framework for assessing readiness and ensuring that safety measures are adequately in place before installation activities.

The findings highlight that a structured safety protocol, when properly implemented, not only mitigates the risk of accidents but also enhances operational efficiency, reduces downtime, and improves team coordination during solar system deployment. In conclusion, integrating proactive risk management tools, such as JSA, risk matrices, and the safety implementation equation, is essential for achieving a safe and successful installation process. Future works may expand this framework to include post-installation monitoring to maintain long-term safety standards.

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