TIRAX

Worksheet W.002

Dismantling Refrigerators

MASTER

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R2M RESEARCH TO MARKET SOLUTION

TI-RAX

Teach Industrial Robotics with AI and XR

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Beneficiaries: University of Cagliari, R2M Solution Srl

Authors: Mirko Marras (University of Cagliari), Andrea Giovanni Martis (University of Cagliari), Diego Reforgiato Recupero (University of Cagliari), Daniele Riboni (University of Cagliari), Giuseppe Scarpi (R2M Solution Srl)

Mentor: Panagiotis Karagiannis (University of Patras)

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Restricted to a specific group of members of the organizations that signed the agreement	
Confidential, only for the appointed contacts	

Learning about Refrigerator Dismantling

Target Audience

This scene targets learners with entry-level technical knowledge and basic familiarity with immersive technologies. It is designed to support initial vocational training and reskilling pathways related to industrial recycling, maintenance, and smart manufacturing contexts.

Learning Objectives

- Understand the main safety, environmental, and operational risks associated with robot-assisted dismantling of refrigerators.
- Recognize and respect interaction zones within human–robot dismantling workspaces, and apply appropriate safety behaviors when entering, operating in, and exiting these areas.
- Cooperate with a robot by assigning, supervising, and understanding dismantling tasks, as well as validating their outcomes as part of a coordinated human–robot workflow.
- Communicate appropriate post-dismantling handling and separation decisions (e.g., component segregation, material isolation) to the robot based on dismantling outcomes.

Short Description

This educational scene is set in a virtual electronic waste recycling environment inspired by realistic dismantling lines for large household appliances. The learner operates within a shared human–robot workspace where a collaborative robot supports refrigerator dismantling and component extraction activities. The learning experience is designed as a guided, scenario-based simulation that develops awareness of safety, environmental, and operational risks associated with robot-assisted dismantling.

Learners are progressively introduced to safe interaction zones and are encouraged to apply appropriate behaviors when entering, operating within, and exiting shared work areas. Throughout the scene, learners actively coordinate dismantling tasks with the robot by assigning operations, supervising execution, and validating dismantling results. Based on the observed outcomes, learners communicate appropriate post-dismantling handling and separation decisions, such as component segregation or material isolation, supporting the development of procedural, safety, and compliance competences.

Role of the Robot

Traditional Manual Dismantling (Without Robots). In conventional WEEE recycling facilities, end-of-life refrigerators were dismantled manually by human operators. Workers approached heavy and bulky units directly, opened casings using mechanical tools, and removed internal components such as compressors, insulation foams, refrigerant pipes, and electronic modules. This required close physical contact with sharp metal edges, pressurized refrigerant circuits, and insulating materials that may contain hazardous blowing agents. Operators were exposed to multiple risks, including cuts, musculoskeletal strain, refrigerant gas inhalation, oil contamination, and fire hazards due to residual electrical charge. Process quality depended strongly on operator experience, physical condition, and time pressure. Dismantling operations were slow, ergonomically demanding, difficult to standardize, and hard to trace.

Robot-Assisted Dismantling (With Robots). In modern recycling plants, robotic dismantling systems reduce direct human exposure to hazardous refrigerator components by physically separating operators from cutting, extraction, and fluid recovery tasks. Refrigerators are first positioned on an automated loading platform at the boundary between the human work area and the robot cell. Once the dismantling sequence is started, the platform transfers the appliance into the restricted robot zone, where a collaborative robot performs controlled opening, component localization, refrigerant line handling, and material separation using integrated vision, force, and gas-detection sensors. The human operator never enters the robot cell during active dismantling and never handles sharp or pressurized parts directly. Instead, the operator remains in a safe corridor and supervises the process through a control console, validating robot actions and selecting the appropriate material routing paths (e.g., metal, plastic, refrigerant, electronic waste). This approach reduces physical risk, prevents environmental release, standardizes dismantling quality, improves traceability, and supports higher throughput.

Operational Parameters

To ensure that the training experience is concrete, repeatable, and implementable, the following operational assumptions define how dismantling cycles, timing, and handling flows are realized.

Dismantling Modes. The robot can perform three predefined dismantling modes:

- *Surface Opening* (outer casing cutting and visual scan, 2 minutes),
- *Component Extraction* (compressor, tubing, and wiring removal, 4 minutes),
- *Emergency Recovery* (rapid refrigerant line isolation and leak detection, 90 seconds).

Dismantling Cycle Duration. Each full dismantling cycle includes:

- Task assignment (10–15 seconds),
- Robot dismantling (according to the selected mode),
- Result visualization (20 seconds),
- Human validation and routing decision (20–30 seconds).

Thus, one complete cycle lasts approximately:

- 3 minutes (Surface Opening),
- 5 minutes (Component Extraction),
- 2.5 minutes (Emergency Recovery).

Material Routing Bins. After validation, dismantled components must be physically routed to one of three material containers:

- *Metal Recovery Bin* (green): casing, frame, and metal components,
- *Electronics Re-routing Bin* (yellow): PCB, wiring, sensors for manual checks,
- *Hazardous Isolation Container* (red): compressor oils, refrigerant lines, contaminated insulation.

Control Console. The control console is the primary human–machine interface of the dismantling system. It is structured as a touch-based panel with three persistent menu sections:

- *Process Menu* (left): controls the dismantling workflow;
- *Status Panel* (right): displays system state and dismantling data;

Process Menu (Workflow Controls).

- `Load Appliance`: confirms that a refrigerator is positioned on the loading platform.

- `Start Dismantling`: opens a submenu to start one of the three dismantling modes.
  - `Surface Opening`: casing cutting and visual scan (2 minutes).
  - `Component Extraction`: compressor, tubing, and wiring removal (4 minutes).
  - `Emergency Recovery`: rapid refrigerant isolation and leak detection (90 seconds).
- `Pause Operation`: temporarily halts robot motion while keeping safety zones active.
- `Cancel Operation`: halts robot motion and deactivates safety zones.
- `Confirm Routing Decision`: finalizes the selected material routing path.
  - `Metal`: sends components to the green metal recovery bin.
  - `Electronics`: sends parts to the yellow electronics bin.
  - `Hazardous`: sends materials to the red isolation container.
- `Emergency Stop`: immediately stops all robot motion and triggers safety alarms.

Status Panel (System Feedback). The right-hand panel of the control console provides both *real-time operational feedback* and *aggregated performance indicators*. It always displays:

- `RobotState` *Values:* {IDLE, OPERATING, PAUSED, ERROR}. *Rationale:* informs the operator of the robot's current execution state and whether interaction is allowed.
- `PhaseProgress` *Range:* 0–100% (progress bar). *Rationale:* shows how much of the active dismantling phase has been completed.
- `SystemAlerts` *Values:* INFO, WARNING, CRITICAL. *Rationale:* communicates safety-relevant events such as gas leaks or tool overload.
- `RefrigerantLeakLevel` *Range:* 0–100 ppm. *Rationale:* monitors the presence of refrigerant gas in the cell.
- `StructuralRiskFlag` *Values:* NONE, MINOR, MAJOR. *Rationale:* summarizes detected deformation, tool resistance, or unstable components.

During performance-driven modules, the same panel also shows a *KPI dashboard* with:

- `TargetCycleTime` *Range:* 2.5–5.0 minutes (mode dependent). *Rationale:* defines the maximum allowed time per dismantling cycle.
- `AvgCycleTime` *Range:* 0–10 minutes. *Rationale:* shows the learner's real operating speed.
- `TargetThroughput` *Range:* 6–12 units/hour. *Rationale:* reflects realistic dismantling productivity targets.
- `ActualThroughput` *Range:* 0–15 units/hour. *Rationale:* measures achieved production rate.
- `SafetyComplianceScore` *Range:* 0–100%. *Rationale:* penalizes unsafe actions and reinforces regulatory compliance.

Training Script

The training activity is designed as a progressive, scenario-based learning experience lasting approximately *five hours*. It is organized into *six sequential modules*, combining guided exploration, hands-on interaction, reflective checkpoints, increasing realism, and formative assessment. The structure supports a gradual transition from basic XR interaction skills to autonomous, safety-critical human–robot collaboration in industrial WEEE dismantling scenarios. Compared to a purely technical tutorial, the training intentionally introduces cognitive load, time pressure, and consequence visualization.

Module 1 – Introduction and Basic Environment Understanding (25 minutes)

Pedagogical Rationale. This module serves as a low-pressure onboarding phase that allows learners to become familiar with the XR environment, basic controls, and spatial layout before engaging in safety-critical or time-sensitive dismantling activities. The focus is on exploration and understanding rather than performance or decision-making. No alarms, emergency situations, or material handling consequences are introduced at this stage.

Learning Outcomes. At the end of this module, the learner will be able to:

- navigate the virtual dismantling workspace using the available controls;
- recognize the main functional areas of the scene;
- interact with objects and interfaces;
- understand where manual interaction is allowed and where robot dismantling occurs;
- recognize visual indicators of robot activity;
- apply basic personal protective equipment before handling appliance components.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner makes a mistake, the system provides hints and demonstrates the correct behavior.

1. *Orientation.* A wall-mounted *facility layout panel* appears next to the learner, showing a top-down view of the dismantling area. The robot cell, dismantling station, human safe corridor, control console, and emergency exit blink one at a time. The learner selects each area in the order shown to build a mental map of the environment.
2. *Movement.* Three floor circles labeled *A* (entry zone), *B* (pre-dismantling table), and *C* (control console) light up in sequence. Direction arrows appear between them. The learner walks to A, then B, then C by stepping into each glowing circle.
3. *Equipment Check.* A personal protective equipment cabinet next to the pre-dismantling table opens and a pair of protective gloves is highlighted. A message appears: *"Wear protective gloves before handling the appliance."* The learner must pick up the gloves and put them on their virtual hands before continuing.
4. *Interaction.* A refrigerator unit is placed on the *pre-dismantling table*, located outside the robot motion area, on the left side of the robot cell. The appliance glows yellow and a *Align* icon appears above it. The *Start Dismantling* button on the nearby console flashes blue. The learner grips the refrigerator, aligns it onto the loading platform, and then presses the flashing button.
5. *Robot Awareness.* The robot arm performs a slow demonstration dismantling movement inside the robot cell. A transparent visual boundary appears around the robot base and arm, and the floor inside this area is highlighted. The learner observes the motion while standing in the safe corridor. This step introduces the concept of robot dismantling zones without risk or time pressure.

6. *Completion.* A checklist appears on the console showing all steps marked as completed. The learner presses *Continue*. This confirms readiness to proceed to safety and dismantling training in the next module.

Learner Monitoring. The system records into a log file: (1) time spent in each step, (2) number of mistakes, (3) navigation errors, (4) PPE compliance, and (5) interaction accuracy.

Module 2 – Safety Boundaries and Hazard Awareness (50 minutes)

Pedagogical Rationale. This module trains learners to behave safely when a robot is dismantling refrigerators in a shared workspace. Unlike Module 1, which introduced static areas and basic robot motion, this module focuses on *dynamic safety conditions*, appliance-specific hazards, warning signals, and timing rules that must be respected during automated dismantling.

Learning Outcomes. At the end of this module, the learner will be able to:

- distinguish safe, collaborative, and restricted robot zones in a dismantling cell;
- recognize dynamic safety boundaries during robot dismantling;
- interpret warning lights, sounds, and color codes related to mechanical and refrigerant risks;
- enter, remain in, and exit shared workspaces safely.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner violates a safety rule, the system blocks progression and explains the correct behavior.

1. *Zone Recognition.* The dismantling cell floor is colored green (safe), yellow (collaborative), and red (restricted). A vertical legend panel appears beside the robot, explaining the meaning of each color and the associated risks (e.g., moving tools, sharp panels, pressurized refrigerant lines). The learner must approach the edge of each zone and select its meaning on the panel.

2. *Dynamic Zone Shift.* The robot starts a slow dismantling motion (e.g., removing the back panel). The yellow collaborative zone expands and contracts around the robot while the red zone remains fixed around the cutting and refrigerant extraction tools. The learner must remain inside the green zone until the robot stops. This step shows that safety boundaries change with robot activity.

3. *Timed Safe Entry.* A traffic-light indicator above the robot alternates between red (do not enter) and green (entry allowed). When the light turns green, the learner must step into the yellow collaborative zone to simulate a manual check. When it turns red again, the learner must return to the green zone. This step trains timing awareness during shared human–robot dismantling.

4. *Restricted Area Violation.* The learner is prompted to attempt entry into the red restricted zone. An alarm sounds, the screen flashes, and the learner is automatically moved back to the green zone. A message explains that the red zone is always forbidden due to cutting tools and pressurized components. This step makes safety rules explicit.

5. *Emergency Exit Procedure.* A flashing arrow appears on the floor and points toward the emergency exit corridor. A simulated refrigerant leak warning is shown on the console. The learner must follow the path and reach the exit marker within a time limit. This step practices evacuation behavior under simulated hazard conditions.

6. *Safety Validation.* A short interactive panel appears on the control console, asking the learner to match zones, colors, hazards, and allowed actions. The learner must answer all questions correctly to proceed. This step confirms safety understanding before dismantling task execution.

Learner Monitoring. The system records into a log file: (1) time spent in each zone, (2) number of boundary violations, (3) reaction time to safety signals, and (4) quiz accuracy.

Module 3 – Human Decisions and Robotic Actions Coordination (60 minutes)

Pedagogical Rationale. This module introduces the complete human–robot *dismantling and classification cycle* for end-of-life refrigerators and trains learners to coordinate their decisions with robotic execution. Unlike previous modules, this phase explicitly connects automated diagnostics and dismantling results to *material treatment paths.* Learners understand that dismantling is not an end in itself, but a decision step that determines how extracted components are processed in the WEEE recycling chain.

Learning Outcomes. At the end of this module, the learner will be able to:

- assign dismantling and inspection tasks to the robot using the control console;
- supervise automated dismantling procedures in real time from safe zones;
- interpret system feedback on refrigerant, compressor, and component status;
- validate robot results and select the corresponding treatment path;
- explain why incorrect validation can lead to safety and environmental risks.

Learning Flow. Each step must be completed successfully before the next one becomes available. If the learner makes a mistake, the system pauses the process and provides corrective feedback. Each dismantling cycle ends with a *guided physical routing action* to a material treatment container.

1. *Guided Observation.* The robot performs a complete dismantling cycle on a refrigerator positioned inside the robot cell while the learner stands in the green safe zone. The control console displays a live status bar showing each phase: panel removal, refrigerant extraction, compressor detachment, and material classification. A short caption explains what the robot is doing at each stage. This step builds an overview of the full workflow.

2. *Task Assignment.* The control console displays three dismantling modes with short descriptions (e.g., standard recovery, deep dismantling, emergency refrigerant extraction). One option is highlighted. The learner selects it to assign the task to the robot. This step teaches how human input initiates robot activity.

3. *Supervised Execution.* The robot starts the dismantling and inspection process. The console shows progress indicators and system messages (e.g., "refrigerant line secured"). The learner must remain in the green safe zone while observing the process. This step reinforces safe supervision behavior.

4. *Result Visualization.* When the dismantling stage ends, diagnostic values and color-coded outcomes appear on the console (e.g., refrigerant recovered, compressor status, hazardous component detected). A short explanation clarifies what the results mean. This step teaches how to interpret robot-generated data.

5. *Human Validation.* The console asks the learner to confirm the robot's classification (e.g., "compressor: reusable" or "refrigerant: hazardous"). The learner must select the correct option to proceed. This step emphasizes that the robot supports decisions but does not replace human responsibility.

6. *Guided Material Routing.* Based on the validated result, the system highlights the corresponding container: *metal recovery bin* (green), *manual inspection crate* (yellow), or *hazardous waste container* (red). The learner must route the extracted component to the highlighted container. A short caption explains why this treatment path is required under WEEE regulations.

7. *Reflection Check.* A short panel asks: *"What could happen if this component is routed to the wrong container?"* The learner selects one answer. This step reinforces awareness of environmental and safety consequences.

8. *Process Confirmation.* A summary of the dismantling and routing cycle appears on the console and the next module is unlocked. This step closes the loop and prepares the learner for risk-based dismantling scenarios.

Learner Monitoring. The system records into a log file: task assignment accuracy, supervision time, validation correctness, routing correctness, safety zone compliance, and reflection response.

Module 4 – Supervised Risk-Based Dismantling Scenarios (75 minutes)

Pedagogical Rationale. This module transitions learners from procedural execution to *risk-aware decision-making* aligned with real industrial refrigerator dismantling and WEEE treatment practices. Learners must not only validate robot-detected hazards and component conditions, but also *physically route* extracted parts into the correct material and hazard treatment paths. Although system guidance is still available, learners must increasingly interpret sensor evidence, manage uncertainty, and understand the safety, environmental, and regulatory consequences of their choices. Small stressors, time constraints, and consequence visualizations are introduced to reflect realistic dismantling conditions.

Learning Outcomes. At the end of this module, the learner will be able to:

- select dismantling sequences based on observed refrigerator risk conditions;
- validate robot-generated diagnostic results under partial guidance;
- route extracted components to the correct physical treatment containers;
- choose and communicate appropriate post-dismantling handling actions;
- explain the safety, environmental, and compliance consequences of incorrect decisions.

Learning Flow. Each case must be completed before the next one is unlocked. Guidance is reduced and mild time pressure is introduced in later steps. All cases end with a mandatory *physical routing action* to a designated container: *green material recovery bin*, *yellow manual treatment crate*, or *red hazardous waste container*.

1. *Case 1 – Standard Refrigerator (Guided).* A refrigerator with no visible damage is placed inside the robot cell. The console highlights the recommended dismantling sequence and the *material recovery* handling option. The learner selects the highlighted dismantling mode, supervises the robot, reviews the diagnostic results (refrigerant safely extracted, compressor intact), and confirms recovery. The system highlights the *green material recovery bin*. The learner must physically route the compressor or metal frame to this container. A feedback panel explains why this path is safe and compliant.

2. *Case 2 – Compressor Oil Leakage (Partially Guided).* A refrigerator showing oil residue under the compressor is placed inside the robot cell. Two dismantling sequences are shown without highlighting. The learner chooses one, supervises execution, and validates the robot's detection of oil contamination. A timer appears on the console. The system highlights the *yellow manual treatment crate*. The learner must physically move the contaminated component to this container. A comparison panel explains the optimal choice and the environmental risks of incorrect routing.

3. *Case 3 – Refrigerant Leak and Foam Contamination (Critical Condition).* A refrigerator with damaged cooling lines and suspected CFC/HC refrigerant leakage is placed inside the robot cell. A warning symbol and low-volume alarm are activated. The learner must select the *emergency dismantling mode*, supervise the robot, and choose *hazardous isolation* as the handling decision. The system highlights the *red hazardous waste container*. The learner must route the extracted foam panel or compressor unit to the hazardous container. If the wrong decision is made, a consequence panel explains the real-world impact (toxic release, regulatory violation).

4. *Micro-Reflection.* A short panel asks: *"Which routing decision most reduced environmental and safety risk in the previous case?"* The learner selects an answer before continuing.

5. *Progressive Challenge.* A random case (standard, oil-contaminated, or refrigerant-leaking) is presented without hints. The learner completes the full workflow independently while background factory noise and a countdown timer are active. The learner must select the dismantling sequence, validate the result, and route the component to the correct container. This step prepares the learner for autonomous operation.

Learner Monitoring. The system records into a log file: case selection accuracy, routing correctness, response time, number of hints used, and critical risk errors.

Module 5 – Autonomous Risk-Based Dismantling and Throughput Management (60 minutes)

Pedagogical Rationale. This module simulates realistic industrial dismantling conditions in which learners must act independently while respecting *production throughput and regulatory recovery constraints*. In addition to safety and correctness, learners must now manage time pressure, environmental compliance, and performance targets, as commonly required in real refrigerator treatment facilities. All guidance is removed and the learner must balance speed, safety, and material recovery quality. The module reinforces professional autonomy, situational awareness, and accountability in WEEE dismantling operations.

Learning Outcomes. At the end of this module, the learner will be able to:

- manage the full robot-assisted dismantling workflow without system prompts;
- maintain processing performance within target time limits;
- respond correctly to safety alerts and unexpected events under time pressure;
- choose and justify handling decisions while balancing risk, compliance, and throughput.

Learning Flow. No visual hints are provided in this module. A live KPI dashboard is always visible on the control console and shows the target dismantling time of **10 minutes per refrigerator**, the target throughput of **6 units per hour**, the average cycle time, the refrigerant recovery compliance rate, and the real-time safety compliance score. The system intervenes only if a critical safety rule is violated, a legal recovery step is skipped, or if the learner exceeds the maximum allowed time.

1. *Timed Autonomous Dismantling Cycles.* A sequence of *four refrigerators* is processed consecutively. For each unit, the learner must select the dismantling mode, start the robot, supervise the extraction of refrigerant and compressor from the safe zone, and review the results on the console. A countdown timer and production progress bar are visible. This step tests the learner's ability to maintain pace while respecting safety and environmental rules.

2. *Unexpected Critical Alert under KPI Pressure.* During one dismantling cycle, a high-priority warning appears indicating a refrigerant leak or compressor rupture. The timer continues running. The learner must immediately select the correct safety response (pause, emergency isolation, or evacuation). If the learner delays or chooses incorrectly, the KPI dashboard shows a safety penalty and a regulatory non-compliance event.

3. *Component Routing under Throughput Constraints.* After each dismantling cycle, the learner must route extracted components (compressor, foam panel, metal frame) to the correct container. The KPI panel updates in real time, showing how each decision affects: (a) environmental compliance score, and (b) average dismantling time. This step makes trade-offs between speed and regulatory correctness explicit.

4. *Justification Check.* After two randomly selected refrigerators, a justification panel asks the learner to explain the chosen handling decision. Incorrect justifications reduce the compliance score, even if throughput targets are met.

5. *KPI Consequence Review.* At the end of the four dismantling cycles, a visual report shows the achieved throughput compared to the target, the refrigerant recovery compliance rate, the number of safety violations, and the number of reworks caused by incorrect decisions. A short explanation connects these values to real WEEE plant performance and legal obligations.

Learner Monitoring. The system records into a log file the (1) average dismantling cycle time, (2) achieved throughput compared to the target, (3) safety response latency, (4) routing accuracy, (5) justification correctness, (6) refrigerant recovery compliance rate, and (7) number of KPI violations.

Module 6 – Assessment, Reflection, and Operational Readiness (30 minutes)

Pedagogical Rationale. This module consolidates learning by transforming dismantling performance data into reflective and regulatory awareness. Learners are evaluated on their ability to act safely, make risk-informed and environmentally compliant decisions, and collaborate with a robotic system under realistic refrigerator dismantling conditions. The module supports transfer to real WEEE plant operations by explicitly linking actions to safety, legal, and environmental consequences.

Learning Outcomes. At the end of this module, the learner will be able to:

- demonstrate safe and compliant robot-assisted refrigerator dismantling behavior;
- interpret operational, safety, and environmental performance feedback;
- reflect on accountability, legal obligations, and human–robot collaboration principles.

Learning Flow. This module is structured as a formal evaluation sequence. No hints, highlights, or corrective guidance are provided.

1. *Final Autonomous Dismantling Scenario.* The learner completes one full refrigerator dismantling cycle under time constraints and background factory noise. All actions are automatically evaluated for safety compliance, refrigerant recovery correctness, procedural accuracy, and response timing. This step generates objective performance data.

2. *Knowledge and Regulatory Reasoning Quiz.* A short XR-based quiz appears on the control console with multiple-choice and scenario-based questions on: safety zones, emergency alerts, refrigerant handling rules, and WEEE compliance obligations. This step assesses conceptual, legal, and applied understanding.

3. *Decision Validation Checkpoint.* The learner is shown a simulated dismantling outcome (e.g., partially recovered refrigerant, damaged compressor) and must select the correct handling and containment decision within a time limit. A consequence preview illustrates the real-world safety, legal, and environmental impact of the choice. This step verifies risk-aware and regulation-aware reasoning.

4. *Performance Dashboard Review.* A visual dashboard summarizes: safety compliance, recovery accuracy, throughput, response time, and critical risk events, with short explanations. This step helps learners understand their operational readiness profile.

5. *Guided Reflection.* A reflective panel asks the learner to confirm key professional principles (e.g., "I am responsible for ensuring full refrigerant recovery before releasing any component"). This step reinforces long-term retention, accountability, and ethical responsibility.

Learner Monitoring. The system stores: (1) final dismantling performance scores, (2) quiz accuracy, (3) decision correctness, (4) reflection selections, (5) safety violations, and (6) refrigerant recovery compliance indicators.

Required 3D Model Assets

The following list includes only the physical 3D models required to implement all six training modules for the *robot-assisted refrigerator dismantling* scenario. It excludes user interface panels, audio elements, shaders, effects, and logic components.

Industrial Environment

- Recycling plant hall / WEEE dismantling facility shell
- Robot dismantling cell structure (enclosed safety cage)
- Refrigerator loading platform at cell boundary
- Manual preparation table (outside robot zone)
- Human safe corridor (rails, floor markings, access gates)
- Control console kiosk
- Emergency exit corridor and safety door
- PPE cabinet
- Wall-mounted plant layout panel
- Vertical safety legend panel

Collaborative Robot System

- Collaborative robot arm (rigged, animated)
- Robot base
- Interchangeable end-effectors:
  - suction/gripper tool,
  - cutting tool for tubing,
  - screwdriver head.
- Refrigerant recovery interface nozzle
- Traffic light tower (red/yellow/green)
- Robot warning beacon

Refrigerators and Components

- Intact refrigerator (sealed system)
- Damaged refrigerator (bent casing, missing panels)
- Leaking refrigerator (refrigerant line breach)
- Compressor unit
- Refrigerant tubing sections
- Condenser coil
- Plastic internal shelves and drawers
- Insulation foam block

Sorting and Containment

- Refrigerant recovery tank (sealed, pressurized)
- Metal components bin
- Plastic components bin
- Hazardous waste container (compressor oil, foam residues)

Safety and Navigation Props

- Floor zone meshes (green, yellow, red)
- Dynamic safety boundary meshes
- Robot safety volume mesh
- Floor arrows and path markers
- Floor target circles (A, B, C)
- Emergency evacuation arrows
- Exit target marker

Human Equipment

- Protective gloves (wearable)
- Safety goggles
- Protective overalls
- Optional: helmet, face shield (future extensions)

Interaction and Scenario Props

- Physical control console housing
- Mode selection panel (physical model)
- Component placement pedestal
- Checklist terminal stand
- Dashboard screen frame
- Reflection kiosk