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APPROVED FOR PUBLIC RELEASE

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7. Abstract

this document provides the criteria for the design of end effectors that will be used as part of the Light Duty Utility Arm System.

8. RELEASE STAMP

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ABREVIATIONS

ASME	AMERICAN SOCIETY OF MECHANICAL ENGINEERS
DOE	DEPARTMENT OF ENERGY
EEES	END EFFECTOR EXCHANGE SYSTEM
LDUA	LIGHT DUTY UTILITY ARM
QAPP	QUALITY ASSURANCE PROGRAM PLAN
TIP	TOOL INTERFACE PLATE
TRIC	TANK RISER INTERFACE AND CONFINEMENT
UST-ID	UNDERGROUND STORAGE TANK - INTEGRATED DEMO
VPM	VERTICAL POSITIONING MAST
WHC	WESTINGHOUSE HANFORD COMPANY

DESIGN CRITERIA FOR THE LIGHT DUTY UTILITY ARM SYSTEM END EFFECTORS

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide criteria for the design of end effectors that will be used as part of the Light Duty Utility Arm (LDUA) integrated system. Actual component design, fabrication, testing, and inspection will be performed by various DOE laboratories, industry, and academia. This document augments WHC-SD-TD-FRD-003, Rev. 0, "Functions and Requirments for the Light Duty Utility Arm Integrated System" (F&R). All requirements dictated in the F&R shall also be applicable in this document. Whenever conflicts arise between this document and the F&R, this document shall take precedence.

1.2 SCOPE

The criteria specified in this document will apply to all end effector systems being developed for use on or with the LDUA system at the Hanford site. This includes end effectors attached directly to the arm, independently deployed end effectors, and all related end effector subsystems. This document will serve as a basis document for the mechanical, electrical, environmental, and safety aspects of end effector design. The requirements stipulated in this document are mandatory. Any deviations from the requirements shall be handled on a case by case basis and formally documented in accordance with WHC engineering practices. End effectors that are being specifically developed for use at other DOE sites shall write separate functions and requirements and may lessen the requirements of this document that are not applicable, such as radiation or environmental requirements.

1.3 BACKGROUND

The United States Department of Energy (DOE) created the Office of Technology Development to assist in the environmental restoration of waste sites across the DOE complex. To complete this task, major development efforts were initiated. One such effort is the Underground Storage Tank Integrated Demonstration (UST-ID). This program is concentrating on the remediation of waste tanks, and is funding the development of a Light Duty Utility Arm system. The LDUA system consists of a robotic arm (which will function as a deployment platform for various surveillance, inspection, and analysis end effectors) and a mobile deployment vehicle to maneuver the system to various waste tanks. End effectors that will assist in these tasks will be developed by DOE laboratories, industry, and academia.

2.0 LDUA SYSTEM DESCRIPTION

2.1 OVERALL DESCRIPTION

The LDUA system consists of a deployment vehicle, a vertical positioning mast, a light duty multi-axis robotic arm, a tank riser interface and confinement, a tool interface plate, a control system, and an operations control trailer. The conceptual design of the overall system is shown in Figure 1.

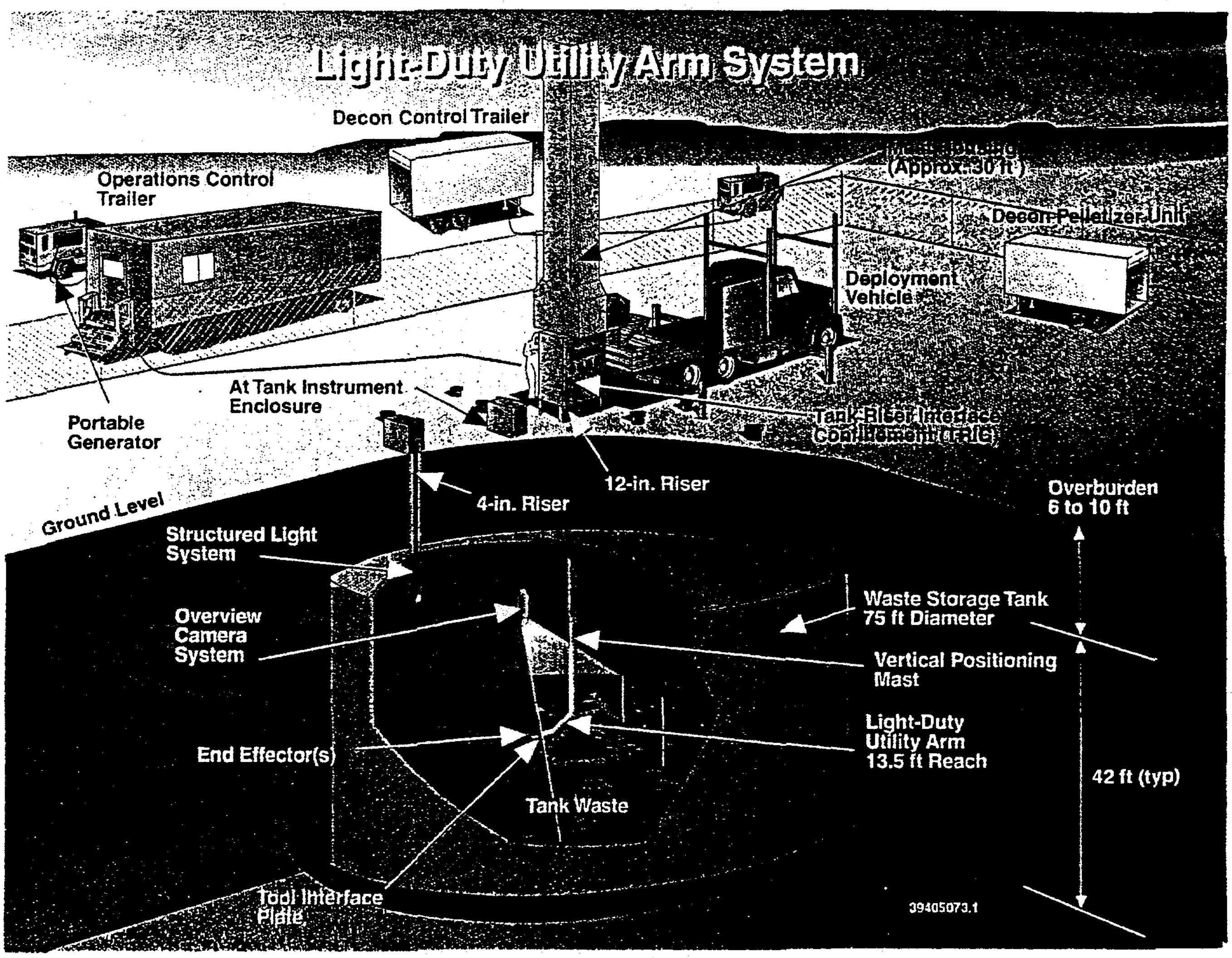

Figure 1 Light Duty Utility Arm System

2.2 DEPLOYMENT VEHICLE

The Deployment Vehicle is a motorized vehicle that will transport the LDUA assembly to the various waste tanks for deployment. It will have the capability to 1) transport the LDUA system to the tank location, 2) upend the LDUA and vertical-deployment systems, 3) position the LDUA over the tank riser, and 4) lower the LDUA into a waste tank. The complete deployment system will be operable utilizing local controls at the deployment vehicle.

2.3 VERTICAL POSITIONING MAST

The Vertical Positioning Mast (VPM) will provide for the gross vertical positioning of the LDUA within the waste tank, and is considered the eighth degree of freedom. It will have infinite speed control, from zero up to at least 15 feet per minute, with a maximum velocity not to exceed 20 feet per minute.

2.4 LIGHT DUTY UTILITY ARM

The LDUA is a seven degree of freedom arm that will have the dexterity to reach beyond obstructions, while providing substantial orientation and positioning capability for the attached end effectors. The LDUA will be capable of orienting attached end effectors perpendicular to any surface within its operating envelope. The operator of the arm will have an infinitely variable speed control to allow precise placement of end effectors during operation. The LDUA is designed to have the following positional error, repeatability, and resolution, at a maximum static payload of 50 pounds, and a moment loading of 1000 inch-pounds at the Tool Interface Plate (TIP) mating surface - positional error of plus or minus 0.5 inches, arm repeatability is plus or minus 0.2 inches from an established starting point, and minimum resolution is 0.05 inches. The maximum static payload of the arm is 75 pounds, with a moment loading of 1000 inch-pounds. The repeatability and resolution are not specified at maximum static payload. The arm will be supplied with a single axis torque sensor (pitch motion) in the arm's shoulder to aid in the control of the end effectors. A six axis force/torque sensor will be provided in the arm's wrist joint.

2.5 TANK RISER INTERFACE AND CONFINEMENT

The Tank Riser Interface and Confinement (TRIC) will provide an interface between the LDUA system and the waste tank riser. It will be used for change-out of end effectors, minor maintenance tasks, and containment of the tank atmosphere. Included will be a decontamination system for the arm and deployed end effectors.

2.6 TOOL INTERFACE PLATE

The TIP provides a common mounting surface for each of the end effectors that will be used in the waste tanks. It consists of two plates, with the master plate located on the wrist of the LDUA, and the slave plate located on the end effector. The LDUA vendor will provide the complete TIP (both master and slave plates). A seal will be provided near the outside diameter of the TIP to seal the interface joint against the tank atmosphere and contents. All of the utilities required for end effector operation will be routed within the sealed diameter of the TIP. The utilities will include common electrical power, instrumentation and control, and fluid (gas and liquid) lines.

2.7 CONTROL SYSTEM

The integrated control and data acquisition system architecture has a supervisory level and a subsystem level. The supervisory level is divided into supervisory control and supervisory data acquisition. The supervisory level is concerned with centralization of control and data acquisition functions and with coordinated operation between subsystems. Supervisory operations are all conducted from the operations and control trailer. End effector subsystems and the TRIC are interfaced with the Supervisory Data Acquisition System (SDAS), and the arm and the End Effector Exchange Subsystem (EEES) is interfaced to the Supervisory Control System (SCS). Subsystem controllers may possess some amount of limited operational capability on their own.

The Supervisory Control Subsystem provides a 3D graphic display as the primary user interface for controlling the LDUA arm. This display allows all motion of the LDUA arm to be previewed against a model of operating environment that defines safe operating areas. LDUA arm motion is checked for collisions. If the previewed motion is collision-free, the operator may approve the motion whereupon the Supervisory Control System directs the LDUA arm subsystem controller to move it.

The Supervisory Control System will be designed to provide for coordinated operations between the LDUA arm and end effectors. It will allow the end user to define such coordinated sequences by means of scripts or other means that do not require modification to the operating software itself.

The Supervisory Data Acquisition Subsystem is able to acquire, process, display, and store data from the end effectors, and can tag this stored information with important operational data such as the identity of the operator, identity of the tank and riser of deployment, and position of the LDUA arm when it was taken.

The Supervisory Data Acquisition Subsystem also provides a means of displaying and recording video information from the end effectors and observational video cameras. The capability to overlay titles and other selected information onto the video is also being provided.

Since several end effectors share a single set of TIP utilities, a means will be provided to automatically switch the appropriate at-tank support electronics to match the end effector mounted on the TIP. This multi-circuit switch shall switch all the electrical circuits in the end-of-arm utilities, and shall support the handling capacity of the end effector exchange system, which is four end effectors.

2.8 OPERATIONS CONTROL CENTER

The operations control center is the command center for the LDUA system. It houses both the equipment and personnel to remotely operate the LDUA integrated system. The operations and control trailer (OCT) will be located outside of the fenced tank farm area and can be up to 900 feet away from the LDUA.

3.0 LDUA OPERATING SCENARIO

The LDUA will be used primarily to deploy surveillance, inspection, and analysis end effectors into single shell waste storage tanks. The types of end effector to be deployed include temperature and moisture sensors, chemical speciation probes, viewing systems, topographical mapping systems, waste sampling tools, and small scale retrieval tools.

When a tank has been identified for inspection, the LDUA system will be transported to the tank using the deployment vehicle. Prior to the arrival of the deployment vehicle to the selected tank, the TRIC will have been aligned and attached to the tank riser. The OCT will also have been positioned outside the tank farm fence and connections made to the TRIC. The deployment vehicle will be positioned near the TRIC, with its outriggers up. Using the low level controller provided on-board the deployment system, the mast housing will be upended, positioned, and aligned to mate with the TRIC. A contamination control boundary will be established between the TRIC and the mast housing using a seal. Air balance controls will be provided by the TRIC. Outriggers for stabilizing the mast housing will be deployed. With the mating to the TRIC complete, the deployment system's umbilical will be connected to the OCT and full control will be transferred over to the supervisory control system inside the OCT.

To initiate a surveillance, inspection, or characterization campaign, an end-effector will be selected for the desired operation. The installation of the end effector to the arm will be accomplished within the TRIC, utilizing a tool change-out mechanism to position the aligned end effector directly below the arm. Operation of the mast and arm will be performed to engage the two tool interface plates (one on the end of the arm and the other on the end of the end-effector). Following end effector attachment, the deployment mast and arm will be lowered from the TRIC, through the decontamination system and into the tank through the tank riser. These operations will usually be performed using the supervisory controller; however, all necessary local controls will be provided to perform all deployment functions at the deployment vehicle location. Other end effector systems deployed separately from the LDUA will also be deployed. The systems will utilize existing 4 inch risers. Each system will have a complete environmental containment. These systems will also be controlled from the OCT.

Operation of the LDUA arm and end effectors inside the waste tank will normally be performed using the supervisory control system; however, the LDUA system will be capable of performing all mast and arm operations in a tele-operated mode using subsystem (low level) controllers and cameras. After lowering the deployment mast to the desired elevation in the tank, the arm will be deployed for positioning end effectors to perform their in-tank functions. It is anticipated that once the system has been deployed in a waste tank, it will operate in that tank for approximately one to two weeks. During this period, multiple end effector change-outs may be performed, without removing the mast housing from the TRIC. Normal decontamination of the mast, arm, and end effectors will take place during these exchanges inside the TRIC.

When in-tank operations have been completed, the mast, arm, and end effector will be decontaminated as they are withdrawn through the decontamination system. The end effector will be deposited on the tool change-out mechanism within the TRIC prior to the arm being retracted into the mast housing. The mast housing will be sealed to contain any residual contamination on the mast and arm before it is detached from the TRIC. The mast housing will then be lowered back onto the deployment vehicle for storage and transport.

4.0 END EFFECTOR DESIGN CRITERIA

Complete end effector systems shall be provided which include the in-tank head assembly, umbilical cabling, at tank instruments and enclosures, control and display electronics, and operating and display software. Various components of these systems will be located in various areas of the tank farm including in-tank, above ground (outside), and in the OCT.

4.1 ENVIRONMENTAL DESIGN CRITERIA

End effector systems shall be capable of normal operation in the environmental conditions given as follows:

4.1.1 TABLE 1 - In-Tank

CONDITION	DESIGN CRITERIA
Ambient Temperature	Normal operation in a temperature range from +50 degrees Fahrenheit to +150 degrees Fahrenheit.
Relative Humidity	Normal operation in a humidity range from 10% to 100%.
Pressure	Normal operation within a pressure range of ± 7 inches of water.
Dust	Normal operation within an environment that may contain abrasive dust in the tank vapor space.
Chemical	Normal operation in a chemical environment that varies from that of concentrated nitric acid fumes to waste material whose pH approaches 14.
Vapors	Tanks may contain an explosive atmosphere and will require design to section 4.3.1 of this document.
Radiation	Normal operation in a radiation field of 2000 rad/hour, for equipment that operates in close proximity (< 3 feet) to the waste surface; or in a radiation field of 1000 rad/hour, for equipment that operates in the vapor space (> 3 feet) above the waste surface. Equipment must be capable of operating properly, without significant degradation in performance, until a minimum accumulated dose of $1 X 10^8$ is attained. For equipment with an inherently low tolerance for radiation, a minimum accumulated dose of $1 X 10^6$ may be acceptable, if change-out of the equipment is sufficiently easy. Radiation cumulative dose requirements may be met by periodic modular replacement of radiation susceptible components.

4.1.2 TABLE 2 - External (Out of Tank)

CONDITION	DESIGN CRITERIA
Ambient Temperature	Normal operation in a temperature range from -20 degrees Fahrenheit to +120 degrees Fahrenheit and shall tolerate additional heat loads resulting from operation in direct sunlight.
Relative Humidity	Normal operation in a humidity range from 4% to 100%.
Wind	Normal operation in wind speeds of up to 40 miles per hour. In addition, the end effector systems shall be able to withstand, without damage, wind speeds up to 80 miles per hour.
Moisture	Normal operation in external rain environments with rainfalls at the rate of up to 2 inches per hour and snow environments with snowfall accumulations of up to 2 feet.
Dust	Normal operation in an environment which has periodic severe dust storms.
Topography	All tank farm equipment must be able to operate (or be leveled to operate) on terraces with slopes up to 10% and berms or curbs up to 6 inches high.

4.1.3 Storage

All end effector systems shall be designed to allow for storage in outdoor containers with internal temperatures ranging from -20 F to +150 F.

4.2 MECHANICAL DESIGN CRITERIA

4.2.1 Safety Factors

All load-bearing components shall be designed with a five-to-one safety factor for lifting points over the ultimate strength (breaking strength). All load bearing components shall be designed with a two-to-one safety factor over the ultimate strength (breaking strength) and one and one half-to-one safety factor over the yield strength other than lifting points.

4.2.2 Material

All structural materials shall be in accordance with ASTM or ASME standards. In-tank components shall be constructed of materials resistant to the tank environment and qualified as spark resistant as much as practical to minimize the use of coatings. Suggested materials include, but are not restricted to, austenitic stainless steel or titanium alloys that have been stress relieved.

4.2.3 Dimensions of End Effectors

End effectors deployed independently of the LDUA are restricted in diameter according to the riser penetration being used. For 4 inch penetrations, the end effector shall fit within a cylindrical envelope no larger in diameter than 3.5 inches. For 12 inch penetrations, the end effector shall fit within a cylindrical envelope no larger in diameter than 10.5 inches.

End effectors deployed on the LDUA shall fit within a cylindrical envelope no larger in diameter than 10.5 inches and no longer than 30 inches inclusive of the end effector portion of the TIP. The end effector portion of the TIP shall be considered to be 4.625 inches in height for initial design purposes.

End effectors shall be designed with smooth contours, chamfers, or lead-ins so that they will not easily become hung up on riser bottoms and other in-tank components.

4.2.4 End Effector Weight Limits

End effectors deployed on the LDUA shall not weigh more than 75 pounds, including the end effector portion of the TIP. This portion of the TIP shall be considered to weigh 15 pounds for initial design purposes. Weight distribution of end effectors shall be configured to limit the moment that is applied to the mating surface between the end effector half and the LDUA half at the TIP to 1000 inch-pounds. In addition, the moment about the wrist roll axis shall not exceed 150 inch-pounds. To attain the repeatability and resolution requirements described in section 2.4 the end effector cannot weigh more than 50 pounds (including the end effector portion of the TIP). There is no weight restrictions on independently deployed end effectors with the exception of riser loading requirements in section 4.2.5.

All end effectors shall be designed for easy lifting depending on their weight. End effectors weighing more than the limit for person lifting shall include lifting fixtures for mechanical lifting.

4.2.5 End Effector Riser Loading

Independently deployed end effectors shall design deployment systems that will not overload the applicable riser load limits. The loading limit for 4 inch risers is 500 pounds maximum. The loading limit for 12 inch risers is 3000 pounds maximum. These are axial loads with a load application point which is not more than 8 feet above the riser flange, or offset from the center line more than 6 inches.

4.2.6 End Effector Design Life

All end effectors shall be designed to have a usable lifetime of 5 years. The mean time between failure shall be no less than 6 months under continuous operation or until total allowable radiation dose limit is reached as described in section 4.1.1. The mean time of repair shall not exceed 24 hours for any component failure or malfunction.

4.2.7 Servicing

End effectors shall be designed to minimize scheduled preventative maintenance. Components shall be selected or substituted where possible to reduce maintenance and increase mean time between failure. End effectors shall be designed without sharp edges, or projections which could cause injury to maintenance personnel.

4.2.8 Contamination Control

End effectors shall be designed and fabricated to facilitate the cleaning of contaminated surfaces. Design shall incorporate smooth surfaces and sealed segments for ease in decontamination.

4.2.9 Maintenance

End effectors shall be designed so the components that are most likely to fail are readily accessible and easily replaced as a unit or as a subassembly. End effectors shall be modular in design to facilitate fast repair cycles by personnel working in anti-contamination clothing.

4.2.10 Lubricants

Nonvolatile, radiation resistant lubricants shall be used for in-tank components. Lubricants must be contained so that the lubricants can not leak into the tank environment.

4.2.11 Actuation

End Effectors may use either electric or pneumatic actuation. The waste tank environment severely restricts the addition of organic compounds during operation and all possible failure modes. Actuation by hydraulics is discouraged, however if provisions are made for leakage control then hydraulic actuation may be allowed. End effectors that use fluids for testing shall have the ability to control that fluid so that there is minimal loss to the waste tank. Methods of testing, types of fluids, and estimated losses to the waste tank shall be provided for Westinghouse Hanford Company (WHC) review and approval prior to Preliminary Design of the end effector.

4.2.12 Decontamination

End effectors shall be designed to allow for decontamination using CO_2 pellets as follows:

Pellet Size	- 1/8 inch diameter by 1/4 inch long
Pellet Density	- 1.56 g/cm^3
Pellet Velocity	- 75 to 1000 feet/second
Flow rate (at nozzle)	- 450 SCFM at 250 psi

End effectors shall be designed to allow for decontamination using a water spray generated by passing 500 psi (maximum) water through a nozzle.

4.3 ELECTRICAL DESIGN CRITERIA

4.3.1 Electrical Design

All electrical design, electrical equipment, electronic equipment, and wiring shall be in accordance with applicable codes and standards. All in-tank end effectors shall be designed to meet the requirements for qualification under the National Electric Code for Class I, Division I, Group B components.

4.3.2 Electrical Enclosures

Enclosures for electrical systems located outside the Operations Control Trailer shall be National Electrical Manufacturers Association (NEMA) Type 4 enclosures for outdoor locations that conform to NEMA ICS-6.

4.3.3 Electrical Equipment and Wiring

End effector providers shall furnish all interconnecting wiring between the LDUA system and their equipment in the Operations Control Trailer, with the exception of the 900 foot umbilical cable which will be provided by WHC. This umbilical will be 62.5 micrometer, multimode, fiber optic cable, with patch panels at each end to facilitate easy connections to the end effector systems. Control and instrumentation wiring shall be separated from power.

4.3.4 Power Loss

The system shall be designed such that a power surge, the loss of electrical power, or the return of lost power shall not result in damage to the end effector system.

4.3.5 TABLE 3 - Available TIP Utilities

Listed below are the available TIP utilities for use by the various end effectors.

UTILITY	# OF CONDUCTORS	SIZE	COMMENTS
Electrical	12	16 AWG (16 Pins)	4 Shielded Triplets
Signal	60	22 AWG (90 Pins)	Twisted/Shielded (30 pair)
Coaxial	2	75 Ohm RG-59U	Coaxial Pin Connector
Coaxial	2	50 Ohm RG-174	Coaxial Pin Connector
Water/Air	3	1/4 inch I.D. Hose (150 psi)	2 for gas purge* 1 air/water
Conduit	1	1/2 inch I.D. flexible	

* To meet the requirements for qualification under the National Electric Code for Class I, Division I, Group B components.

4.3.6 TIP Attachment

The TIP master and slave assemblies will be designed and fabricated by the LDUA developer. This task has not yet been completed, therefore the end effector providers who will be using the TIP, must allow for interface changes when the final design of the TIP is implemented.

4.4 SOFTWARE DESIGN CRITERIA

All end effector system software shall be in accordance with the LDUA Software Development Plan, Westinghouse Hanford Company document WHC-SD-TD-SDP-001.

5.0 APPLICABLE CODES AND STANDARDS

Applicable codes and standards shall be used in the design of all end effectors. The most current codes, standards, and orders shall be used. End effector systems shall be designed to meet or exceed the requirements of the listed codes and standards. All reference documents listed below shall be the latest revision as of January 1, 1994.

5.1 MATERIALS

The ASTM specification shall be documented for the 300 Series Stainless Steels and other materials that are selected for the fabrication of any component or structure in the end effector.

5.2 ELECTRONICS AND COMMUNICATION

Electronic Industrial Association

RS-232	Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange
RS-281	Electrical and Construction Standards for Numerical Machine Control
RS-449	General Purpose 37 Position and 9 Position Interface for Data Terminal Equipment and Data Circuit Terminating Equipment Employing Serial Binary Data Interchange.
RS-422-A	Electrical Characteristics of Balanced Voltage Digital Interface circuits
RS-423-A	Electrical characteristics of unbalanced voltage digital interface circuits

5.3 ELECTRICAL

National Electrical Manufacturers Association (NEMA)

ICS 1	Industrial Controls and Systems
ICS 6	Enclosures for Industrial Controls and Systems

5.4 FIRE PROTECTION

National Fire Protection Association (NFPA)

70	National Electric Code (NEC)

5.5 SAFETY

Occupational Safety and Health Administration (OSHA)

29 CFR 1910	Occupational Safety and Health Standards

5.6 SOFTWARE

Institute of Electrical and Electronics Engineers (IEEE)

829 IEEE	Standard for Software Test Documentation
830 IEEE	Guide to Software Requirements Specifications
1063 IEEE	User Documentation
983 IEEE	Guide for Software QA Plans

American National Standards Institute (ANSI)
American Nuclear Society (ANS)

ANSI/ANS 10.4	Verification and validation of scientific and engineering computer programs.

5.7 DESIGN

ANSI Y14.5M	Dimensioning and Tolerancing
SDC-1.3	Preparation and Control of Engineering and Fabrication Drawing

5.8 MACHINING

ANSI B46.1	Surface Finishes
ASA B1.1	Screw Threads

5.9 WELDING

American Welding Society (AWS)

AWS D1.1	Structural Welding Code for Steel
AWS A2.4	Weld Symbols

6.0 SAFETY

All aspects of safety shall be considered in the design of end effector systems. End effector designs will undergo safety analysis according to the LDUA System Safety Program Plan, WHC-SD-WM-WP-231.

7.0 QUALITY ASSURANCE

Quality Assurance/Control activities for all end effector providers involved in the design, fabrication, and acceptance testing shall be executed in accordance with the LDUA Quality Assurance Program Plan (QAPP) (WHC-SD-WM-QAPP-022). The QAPP shall be used to develop verification criteria in design documents, i.e., drawings, specifications, test procedures, and to define quality assurance interfaces.

8.0 REFERENCES

1. WHC-SD-TD-FRD-003, Functions and Requirements for the Light Duty Utility Arm Integrated System, Westinghouse Hanford Co., Richland, Washington, 1994.

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