MICROELECTRONICS

RECYCLING HIGH-PURITY RINSEWATER AT SAMSUNG AUSTIN SEMICONDUCTOR

Articles have been written for more than a decade about the benefit and need for water conservation in the semiconductor industry. A large fab can easily consume more than 1.5 million gallons of water per day supplied by a local municipality. This issue is magnified by the fact that many fabs in the United States are located in drier climates.

For a variety of reasons (i.e., money, local regulations, ISO compliance, and good citizenship), almost all fabs have initiated water conservation efforts and many have commissioned task force teams to reduce fab consumption. Some fabs have taken the next step to start capturing some of the water used in the wafer production process and reclaiming the water for other purposes. However, few have taken the next step to directly reduce the burden on municipal water supplies by recycling the production water back into the purification plant from which the water came.

Years of experience with water recycling efforts in South Korea have aided the Samsung Fab in Austin, Texas. In Austin, SAS has built an impressive track record over the past 7 years of minimizing city water consumption through an intensive water-recycling program that involves the efforts of every employee in the company. Samsung estimates that the current water-recycling program is responsible for reducing city water demand by more than 120 million gallons annually.

This article explores techniques used by Samsung Austin Semiconductor (SAS) to achieve this level of water reclamation. The Samsung approach will show that great success can be achieved through water recycling while returning bottom line dollars back to company. Every site will have unique constraints (as well as opportunities) that will influence their ability to reclaim water. The concepts are presented as building blocks for structuring a recycling program and give insight to one fab's success story.

Site Background. Samsung Austin Semiconductor is a high-volume dynamic random access memory (DRAM) semiconductor manufacturer. DRAM production at this facility began in 1997 and has grown ever since. The SAS DRAM manufacturing process consumes more than 1 million gallons of high-purity water per day. Recent data has placed the water consumption per wafer at just over 700 gallons. The high-purity water plant contains all the unit processes necessary in a semiconductor setting: several pass RO, ion exchange, degasification, and ultraviolet light, among others. One unique aspect of the SAS high-purity water process is the direct recycle of fab rinsewater back into the make-up portion of the water plant.

The SAS high-purity water plant relies heavily on the recycled water from the DRAM production process. The front-end RO capacity is limited to 700 gallons per minute (gpm). In October 2004, with the fab high-purity water consumption rate eclipsing 775 gpm, and sustained peaks above 850 gpm, recycled water was a necessity to sustain the continuous operations of the system. To ensure the integrity and reliability of the recycled water, SAS has developed and refined the site water recycle program.

The site water recycle program consists of four tenets, all of which play significant roles in the success of the SAS recycle program. The program has been successful in recovering more than 1 billion gallons of water directly back to the high-purity water process over the past seven years. As of the publishing of this article, the recycle water program has never contributed to an out of specification condition of the fab water supply parameters: TOC, ions, and resistivity. The four tenets of the SAS recycling program are system design, water management strategy, effective communication, and company commitment. Each tenet will be explored in detail.

Tenet #1: System Design

Any dependable high-purity water system should be designed to operate efficiently under normal operating conditions. In addition, a high-purity water system that operates with recycle streams must possess the design robustness to handle process upsets that can occur much more frequently than that of municipal water supplies because of the dynamic rinse stream characteristics of a fab. A recycle system design starts with a drain collection system. Polyvinyl chloride (PVC) will suffice for most applications, but temperature and the pH of recycle streams

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TABLE A
SAS Water Recycle Metrics*

Fab Metrics	*Gallons/Day*	*% of Total*
High-purity water consumption	1,070,000	
Waste	558,800	54%
Recycle	468,000	44%
Reclaim	43,200	4%
Total reuse	511,200	48%

*September 2004

should be taken into account when selecting materials of construction. The Samsung recovery system consists of the following:

- Neutral 1 and Neutral 2 PVC drain collection piping
- 6,000-gallon local recovery tank
- 10,000-gallon recovery storage tank
- Conductivity meter
- TOC monitor
- Pneumatically actuated butterfly valves
- Manually operated butterfly valves

The layout of this equipment can be seen in Figure 1. The theory of operation is as follows:

Rinse water is collected in the Neutral 1 and Neutral 2 drain piping and gravity fed out of the fab to the Local Recovery Tank

The Neutral 1 and Neutral 2 recycle streams can be manually diverted to or away from the Local Recovery Tank (typically used in conjunction with coordinated activities).

Pumps direct the local recovery water to the Recovery Storage Tank This second tank in the recovery system is necessary because of the time delay of the total organic carbon (TOC) instrumentation. TOC and conductivity measurements are monitored within this pressurized line. To prevent contamination of the Pretreated Water Pit, the following control scenario is followed:

First, a conductivity reading above a designated set point will actuate the pneumatic valves entering the Recovery Storage Tank, or divert the water away.

Second, a TOC reading above a specified set point will force the same valve actuation as a high conductivity reading as well as open the drain valve on the recovery storage tank. The tank is drained to prevent any high TOC water that may have entered the Recovery Storage Tank since the last TOC reading from entering the high-purity water make-up system.

Recycled water in the Recovery Storage tank overflows into the Pretreated Pit. At this location, the recycled water combines with reverse osmosis number 1 (RO#1) permeate to supply the downstream process equipment that consists of activated carbon filtration and single bed cation- and anion-exchange resin towers.

Samsung has used the two-tank operation with great success to maximize water volume while minimizing risk. Employing this recycle strategy, SAS has achieved results visible in Figure 2.

Tenet #2

A semiconductor fab requires water for a variety of processes. The high-purity water plant makeup is typically the largest need. Other prerequisites include boiler make-up, air abatement scrubber makeup, and cooling tower condenser water makeup, among others. Often, reclaim water with little or no treatment is sufficient for these needs. An understanding of the water quality and quantity that each of these unit processes requires is fundamental for a successful water recycling/reclamation program. The first step in this strategy is to establish a site water mass balance.

Maintain site water balance. The site water balance is a fundamental aspect required during the fab's initial design process. Once established, the water balance should be maintained and updated on a periodic basis. Each month at SAS, the incoming water, and outgoing wastewater bills are reconciled against the other various influxes and outfalls of water around the site. After the overall mass balance is satisfied, the internal streams are then balanced for water continuity. These mass balances serve as sanity checks for any recycling/reuse water program. Changes to one stream in the program can be crosschecked against the other streams in the program for adverse effects. After the mass balance is satisfied, the next step is to develop a cost of ownership model for the various streams in the water balance. Simply, what is the cost to replace this water should this recycle stream be diverted elsewhere in the water balance?

Develop cost of ownership model of recycle water. All water that is consumed in the semiconductor production process is not cost effective to recycle or even reclaim. A cost effective approach is necessary to identify which rinse streams should be targeted for recycle. This is accomplished by establishing a *replacement cost* for water at any point in the production process. The replacement cost model should include raw water cost, wastewater treatment cost, and plant operation cost (labor, utilities, consumables). Table A provides an overview of the SAS water recycle metrics.

When the replacement cost model is established, a return on investment (ROI) calculation can be performed on potential recycle locations in the high-purity water plant. Figure 3 shows the breakeven point for rinse water conductivities that enter the SAS Facility post the first RO process. The replacement cost for the SAS facility of POU quality water is approximately $8.50 per 1,000 gallons. By measuring the effects of conductivity or recycled water, it is determined that recovered water in excess of 1,460 microsiemens per centimeter (μS/cm) should not be targeted for recycle.

TOC, dissolved silica, and suspended solids should also be considered, but the cost of ownership model is much more complex. Membrane and resin fouling, maintenance and replacement costs, and overall water quality must be evaluated in much more detail with these contaminates. SAS simply establishes a go/no-go condition for recycle streams that have elevated levels of these contaminants. Once the replacement cost model is established, the next step is to characterize and compare individual rinse streams to the model in order to determine whether they are suitable for recovery or not.

Characterize waste streams. As previously mentioned, Samsung monitors the conductivity of the Neutral 1 and Neutral 2 drain systems entering the local recovery tank. After the streams are combined at the local recovery tank, the TOC and the conductivity are measured with online analyzers. Periodically, a composite sample will be taken and sent to the lab for detailed ions and organic carbon analysis. A 24-hour composite sample of the SAS Neutral 1 and Neutral 2 combined recycle stream is compared against the incoming City of Austin water in Table B.

All potential recycle rinse streams are characterized to determine the average and peak contamination levels. Depending on fab loading, both of these values are of interest. SAS has found that conductivity and TOC measurements over a 24-hour period offer sufficient data to see inherent process devi-

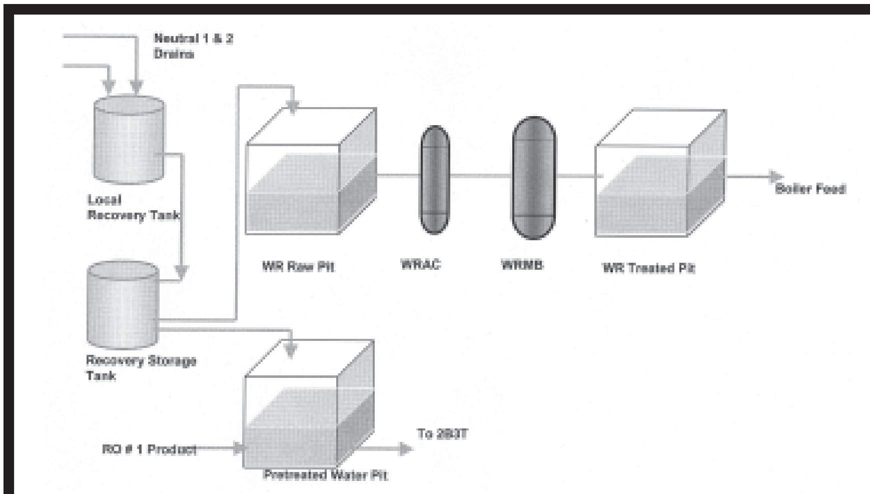

Figure 1. Water recovery system at SAS.

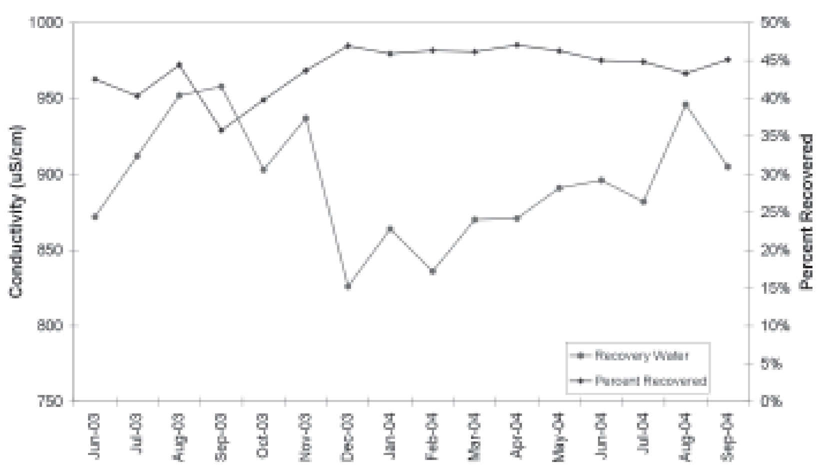

Figure 2. Samsung recovered water quality chart.

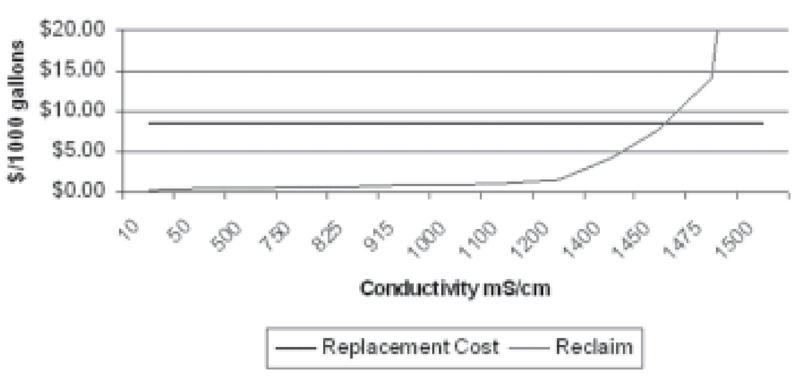

Figure 3. Replacement cost model chart.

ations. If the process tool is subject to numerous upsets or unusual process conditions, additional data may be taken. One method employed by SAS is to sample the tool's drain line directly. A small ball valve is installed on the drain line near the fab level. Sample tubing is extended to the fab's sub floor and connected to the monitoring instrument. Please note that a p-trap installation may be required to ensure sufficient sample water is available for the monitoring instrument. Figure 4 depicts the p-trap sampling configuration used at SAS.

SAS has found success in recycling the following rinse streams that comply with the cost effectiveness model. The streams recycled at SAS consist of the following: wafer scrubbers, quick dump rinse baths, wet bench robot storage/cleaning baths, final rinse baths, and instrumentation streams.

Waste streams at SAS that presently do not fit the cost effectiveness model are from photolithography and chemical mechanical polish (CMP). For example, the high particulate and silica content of the CMP waste stream make this stream undesirable because of the potential effects on downstream plant equipment. The return on investment for the additional equipment necessary to remove these components does not meet the current company expectations for investment capital.

After the targeted recycle streams have been identified, many factors will determine the success of using these recycle streams in the high-purity water production process. Once the rinse streams are in the collection system, the high-purity water plant operators must maintain the controls. To assist the operations team, SAS has tried to optimize the recycle streams to minimize the possibility of upsets and maximize recovery.

Optimizing recycle streams. At SAS, wet benches consume more than 80% of the high-purity water usage in the fab. From the beginning, the quick dump rinse (QDR) baths and final rinse baths have been the focus of the SAS recycle program. Figure 5 shows the cross section of a typical wet bench as SAS. Chemical bath labeled (HS-1, HS-2, SC-1, HF) are followed by QDR baths. After the last QDR bath, the wafers enter a final rinse bath before one last cleaning step before entering a dryer.

The QDR baths function to remove residual chemical from the wafers as they move from one chemical bath to the next. Much research in the industry has focused on optimizing the QDR sequence to minimize the number of cycles required for each QDR step. This research also applies to the reclamation of the rinse water discharged after each QDR cycle. As the QRD cycles increase, the water quality of the rinse stream also increases, making this water very attractive to recycle. At SAS, all but the first dump is recycled into the Neutral 1 drain collection system. However, the biggest challenge SAS has faced in the recycling of water from these wet benches has been from an unlikely source, the final rinse baths.

Final rinse baths. By design**,** final rinse baths should present the most plausible source for recycle water of all the potential sources in a fab. The final rinse bath will follow a QDR bath and acts as the last rinse before the wafers leave the wet bench and enter a dryer. The final rinse water typically exceeds 17 megohm-cm when discharged into the Neutral 2 drain system. However, even with this low ionic load, Samsung encounters a different issue when recycling the final rinse water. Because of the physical location, the final rinse bath is in close proximity of the dryer that uses isopropyl alcohol (IPA). SAS has found a wide discrepancy in the levels of IPA dissolved in the final rinse water baths of wet benches - from low-parts per billion (ppb) levels to the several parts per million (ppm) levels. SAS has investigated this wide disparity in IPA levels and the following results have been documented.

SAS investigated three main variables thought to contribute to the disparity in the IPA levels within the different final rinse baths. A design of experiment (DOE) was conducted with these variables to evaluate their effects on the IPC levels in the final rinse baths. The three factors were dryer type, shutter, and string angle. These factors and the levels of the DOE are listed in Table C.

The DOE considered the average and standard deviation of theTOC value. The interaction plot (Figure 6) shows the main effects and interaction of the main variables on the overall TOC level.

The interaction plot shows dryer type accounts for the largest contributor to TOC level. However, the contribution of TOC is not the primary selection criteria for the dryer type. This requires that our analysis treat any dryer added TOC contribution as a noise variable. Shutter placement results showed little importance on the overall TOC level present in the Neutral 2 drains. The string angle is a crude attempt to characterize the exhaust imbalance between the final rinse bath and the IPA dryer. The test was conducted at angles of inclination approximately measured at 15, 5, and 0 degrees.

Table D summarizes the mean and peak data points for each run. In each condition, a spike in TOC can be correlated to a wafer lot entering or exiting the IPA dryer. However, the average TOC was reduced by greater than 60% and the peak TOC was reduced by 17% when comparing a balanced, 0 degree angle, versus an unbalanced, 15 degree exhaust condition. Remember, the recycle system is designed to handle TOC spikes by diverting high TOC water. The goal of is to reduce the average TOC levels.

TABLE B
Comparison of SAS Recycle versus Incoming City Water

ConstituentConcentration in ppm $CaCO_3$		
Anions and Cations	*City Make-up*	*SAS Recycle*
Fluoride	2.2	4.5
Chloride	71	<0.1
Nitrite	<0.05	<0.05
Nitrate	0.11	<0.05
Sulfate	36	135
Phosphate	<0.05	12
Bicarbonate	33	<2
Carbonate	24	<2
Hydroxide	<10	<10
Sodium	57	<0.1
Ammonium	0.56	3.9
Potassium	4	<0.05
Magnesium	76	<0.05
Calcium	32	0.18

TABLE C
Wet Bench DOE Factors and Levels

Factor	*High Level*	*Low Level*
Dryer type	vapor cloud	yield-up
Shutter	yes	no
String angle	0	15

TABLE D
Summary of Wet Bench DOE

Condition #	*String Angle*	*Average TOC (ppb)*	*Peak TOC (ppb)*
0	15 degrees	1,038	1,710
1	5 degrees	579	1,550
2	0 degrees	387	1,410

Tenet #3

Communication between departments, particularly between the process tool owners, maintenance and installation personnel, and the high-purity water plant operations team is vital to the success of the recycle program. To force communication between the teams since the drain collection systems are critical to sustaining the high-purity water treatment plant's operation, SAS has made each group accountable for the success of the recycle program. Figure 7 shows the new equipment safety sign-off form.

After a few missteps in the early years of fab operation, the reliance of all parties on each other was quickly realized. A complete loss of recovery would result in a fab shutdown in less than 24 hours. Key communication events that are crucial for recycle operation, including the following:

- Drain repairs: PVC glue contains a high organic compound.
- Local tool hydrogen peroxide sterilizations: Hydrogen peroxide can be devastating to the short-term TOC removal efficiency of the activated carbon filters.
- New recovery drain connections: To ensure no unauthorized or potential risky connections are made to the recovery system, the high-purity process owner's signature must appear on the tool sign-off form before the

Figure 4. Photo depicting sample drain configuration.

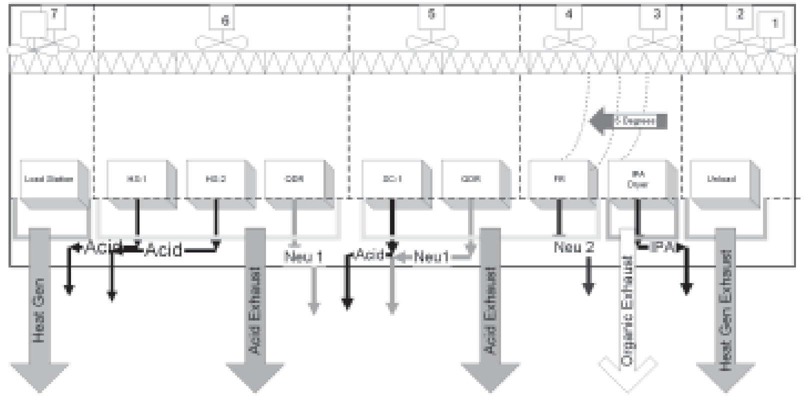

Figure 5. Typical wet bench cross section.

tool is allowed for a power-up condition. Samsung's commitment is demonstrated by granting equal weight to the production tool's sign-off form. All disciplines, electrical, mechanical, chemical, DI water process, process drains, etc. are required prior to allowing the start up of the process equipment

Tenet # 4

Company commitment is by far the hardest to measure of all tenets. Commitment by definition is a subjective term. Commitment comes in two forms at SAS— people and money. Most companies are committed to a clean environment. This commitment often stops when the commitment means additional resources above and beyond what is required to meet minimum standards. SAS has taken a different approach, and has reaped the benefits of a cost-effective, top-down driven water recycle program.

Top-down approach. The success of most business initiatives starts with a top-down approach. If executive management is not committed to an initiative, either to approve capital funds or authorize valuable human resources, initiatives often fail. At SAS, the Environment Health and Safety (EHS), and Utility Engineering Management have played key roles in the water recovery efforts. In addition to EHS, the SAS company president has served several terms as a member of the Texas Water Foundation Board. Along with serving the community, more than $2,000,000 was appropriated during the base construction strictly for water reclamation infrastructure. To date, another $500,000 has been spent to enhance and maintain this investment. Money will always play a central role in the success of a water-recycling program.

Along with executive management, the EHS and public relations departments play a substantial role in SAS's water recycling program. As an ISO-14000 certified company, SAS has made a commitment to the community to lessen the fab's impact on the environment, thus promoting water conservation efforts and initiatives through internal training. This training raised overall employee awareness of the importance of water conservation and what each and every one can do to contribute to the program's success. Once again, valuable training time is needed to achieve site awareness.

The public relations department role extends beyond the EHS training. Their efforts have resulted in SAS being featured several times on the local news stations and articles in the local paper for successful water conservation initiatives. Because of the importance of water in this community, the SAS image of a good steward of the municipal water supply has a countless positive impact on the image of the company in the local community.

Summary

Water reclamation has been an integral part of the Samsung Austin high-purity water process since the inception of the fab in 1997. As fab demands have changed over the years, the water recovery program has changed to meet the new challenges. The SAS program consists of four tenets, all of which are critical to the success of the program. Through the efforts of dedicated people and a sound water reclamation program, SAS has conserved more than 1 billion gallons of city water! Future recycle projects have already been funded to ensure SAS continues to lead the way in minimizing the impact of the water plant on the local community and environment.

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Coauthor Ed Lickteig received a B.S. in mechanical engineer from the University of Oklahoma. He began his professional career with Samsung Austin Semiconductor in 1997. Initially, Mr. Lickteig began with Samsung as a process engineer, prior to working in the Utility Engineering department. Since the fall of 2001, his primary responsibility has been the managing the operations of SAS high-purity water and IWT plants.

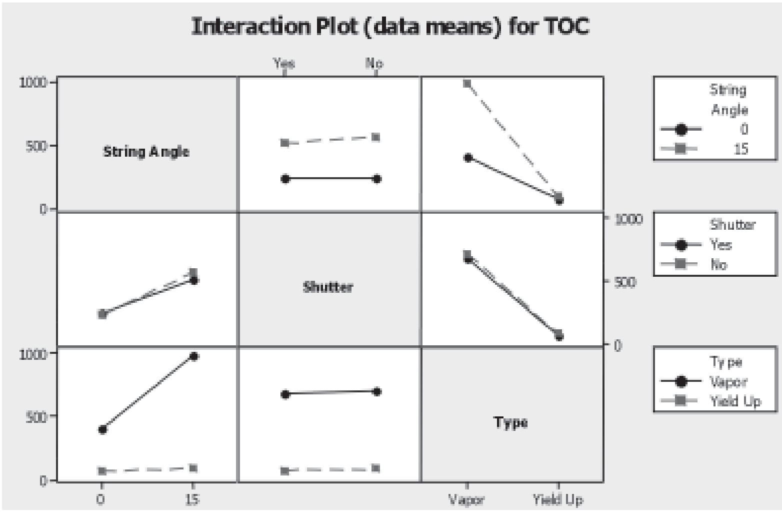

Figure 6. Wet bench DOE interaction plot.

SAMSUNG
AUSTIN SEMICONDUCTOR

Equipment Start-Up Authorization

Equipment Information

Fab ________ Area ______________________________ Bay ____________ Tool ID [ ]

Equipment ________________________ Manufacturer ______________________ Model ____________________

Moved-in & Set

	Print Name & Identify Company or Dept.	Signature	Date	Pager
1. Riggers				
2. Line Planning				
3. SAS Engineer				

Initial Signoff

	Print Name & Identify Company or Dept.	Signature	Date	Pager
1. Electrical				
2. Equipment Vendor				
3. SAS Engineer				
4. SAS Facilities Electrical				
5. SAS Safety/Consultant				

Final Signoff

	Print Name & Identify Company or Dept.	Signature	Date	Pager
1. Liquid Chemical Piping				
2. Spec Gas Piping				
3. Bulk Gas Piping				
4. DI Water Piping				
5. DI Water Process				
6. Drains				
7. Exhaust Duct Install				
8. Exhaust Duct Balance				
9. Gas Detection				
10. Fire Protection				
11. SAS Facilities Electrical				
12. Equipment Vendor				
13. SAS Engineer				
14. Visual Line Verification				
15. Safety Consultant				
16. SAS Safety				
17. SAS Safety Log/Label				

Equipment Safety Checklist and Signoff Authorization Form (Rev 3.0 – [illegible]) Page 1

Figure 7. New equipment safety sign-off form.

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