DOE/NV/03624--1051

Assessing the Potential for Inadvertent Human Intrusion at the Area 3 and Area 5 Radioactive Waste Management Sites on the Nevada National Security Site, Nye County, Nevada

April 2021

Prepared By

MISSION SUPPORT AND TEST SERVICES LLC

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U.S. Department of Energy
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Executive Summary

This paper recommends an approach to inadvertent human intrusion (IHI) at the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) on the Nevada National Security Site (NNSS). IHI analysis uses the consequences of an individual inadvertently contacting buried waste to set waste concentration limits for near-surface disposal of low-level radioactive waste (LLW). Regulatory agencies are increasingly applying risk-informed decision-making to LLW waste management (NRC 2006). Risk-informed decision-making combines scientific risk assessment with stakeholder values and perceptions to determine a level of acceptable risk. Risk considers not only the consequences of an event, but also its probability of occurring.

IHI analysis typically assumes that intrusion is certain to occur and do not evaluate intruder risk. The NNSS occupies one of the least populated regions of the US. Yucca Flat and Frenchman Flat, the respective sites of the Area 3 and Area 5 RWMSs, have no history of long-term human settlement. Attractive resources, including surface water, shallow groundwater, minerals, petroleum, irrigable cropland, or quality rangeland do not occur at or near the Area 3 or Area 5 RWMSs. The probability that a unique or valuable resource will attract an intruder to the RWMSs in the next 1,000 years appears to be much less than 1.0.

The US Department of Energy (DOE) and the National Nuclear Security Administration/Nevada Field Office (NNSA/NFO) have formal policies to implement and maintain institutional controls that minimize the potential exposure to residual radioactive contamination as long as the hazard remains. Sites on the NNSS with residual radioactive contamination from past operations are closed under the Federal Facility Agreement and Consent Order (FFACO) among DOE, the Department of Defense (DoD) and state of Nevada. Closed FFACO sites with residual contamination exceeding clean-up standards are subject to institutional controls, known as use restrictions (URs), negotiated with the state of Nevada. The FFACO closure of Underground Test Areas (UGTAs) assumes that URs will be effective for 1,000 years. The NNSA/NFO has made formal commitments to enforce institutional controls as long as they are necessary.

Subject matter experts (SMEs) evaluating the probability of IHI at the NNSS proposed that the most probable scenario for IHI at the RWMSs was conditional on the development of a community near Yucca Flat or Frenchman Flat. The SMEs proposed that a nearby community could support rural residents in Yucca and Frenchman Flat and that rural residences would begin to be constructed at random locations. Stochastic simulation of this scenario, including the effects of institutional controls, suggests a mean 1,000-year probability of drilling intrusion of 0.2% at the Area 3 RWMS and 8% at the Area 5 RWMS. The 1,000-year probability of construction intrusion was slightly less, 0.1% and 6% at the Area 3 and Area 5 RWMSs, respectively.

Review of conditions at the NNSS indicates that the potential for IHI at the RWMS is low. Factors reducing the potential for IHI include the lack of attractive resources near the RWMSs, the sparse settlement of the remote alluvium filled valleys of the region, and DOE commitments to use and maintain institutional controls. Stakeholders have accepted institutional controls for management of NNSS legacy contamination. This paper recommends six assumptions regarding implementation of IHI analysis in the Area 3 and Area 5 RWMSs performance assessments and composite analyses.

1. DOE, NNSA/NFO, and its successors will implement, maintain, and enforce institutional controls consistent with their policies and directives, including FFACO policies and use restrictions (URs), at the Area 3 and Area 5 RWMSs as long as a hazard persists.
2. FFACO UGTA URs at the Area 3 RWMS will prohibit public access to contaminated groundwater within the Nevada Department of Environmental Protection (NDEP) negotiated compliance boundaries for 1,000 years. Similarly, NNSA/NFO institutional controls and FFACO URs on the Area 5 Radioactive Waste Management Complex (RWMC) will prohibit access for 1,000 years.
3. The low probability of intrusion combined with URs prohibiting access will eliminate the potential for long-term chronic intrusion. The Area 3 and Area 5 RWMS performance assessments will not evaluate chronic post-drilling and chronic construction (i.e., intruder-agriculture) intrusion scenarios. Institutional controls will not be 100% effective for shorter time spans (months) and will not prevent occurrence of acute drilling and construction scenarios.
4. The performance assessments will stochastically sample the duration of active and passive institutional controls from probability distributions based on the results of a site-specific SME elicitation. The lower limit of the institutional control period will be truncated at 100 years for DOE 435.1 performance assessments. The duration of institutional controls will remain fixed at 100 years for Title 40, Code of Federal Regulations Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," performance assessments.
5. FFACO URs are assumed to eliminate use of groundwater contaminated by underground testing for 1,000 years. This is assumed to eliminate the UGTA groundwater pathway from the composite analysis.
6. A quantitative probability of IHI will not be applied in risk-modified dose calculations consistent with the guidance of the National Academy of Sciences (NRC 1995).

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Acronyms and Abbreviations

AUM	animal unit month
BLM	Bureau of Land Management
CAS	corrective action site
CAU	corrective action unit
DoD	US Department of Defense
DOE	US Department of Energy
DOE/NNSA	US Department of Energy/ National Nuclear Security Administration
DWNR	Desert Wildlife National Refuge
FFACO	Federal Facility Agreement and Consent Order
ha	hectare(s)
IAEA	International Atomic Energy Administration
IC	institutional control
IHI	inadvertent human intrusion
km	kilometer(s)
km^2	square kilometer(s)
LLW	low-level radioactive waste
$L\ min^{-1}$	liters per minute
m	meter(s)
NBMG	Nevada Bureau of Mines and Geology
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NNSA/NFO	National Nuclear Security Administration/Nevada Field Office
NNSS	Nevada National Security Site
NRC	National Research Council
NTTR	Nevada Test and Training Range
REOP	real estate operations permit
RWMC	radioactive waste management complex
RWMS	radioactive waste management site
SLB	shallow land burial
SME	subject matter expert
UGTA	Underground Test Area
UR	use restriction
USNRC	US Nuclear Regulatory Commission
UTM	Universal Transverse Mercator

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1.0 Introduction

Regulators categorize low-level radioactive waste (LLW) based on the hazards posed to an inadvertent human intruder (US Nuclear Regulatory Commission [USNRC] 1982, US Department of Energy [DOE] 2011). Inadvertent human intrusion (IHI) analysis estimates the consequences of an individual unknowingly contacting buried radioactive waste. The IHI results are used to establish radionuclide concentration limits that are acceptable for near surface disposal.

LLW disposal facilities sited in highly populated regions may have a probability of intrusion approaching 1.0 in 1,000 years. The arid deserts of southern Nevada have very low population densities. Some valleys within the Nevada National Security Site (NNSS) have no record of permanent human settlement before establishment of the Nevada Test Site. Assuming intrusion will occur with probability of 1.0 in 1,000 years may be unreasonable for NNSS valleys. Regulatory agencies are increasingly applying risk-informed decision-making to LLW waste management (National Research Council [NRC] 2006). Risk-informed decision-making combines scientific risk assessment with stakeholder values and perceptions to determine a level of acceptable risk. Risk considers not only the hazard of an event, but also its probability of occurring.

Crowe et al. 2007 considered the effect of institutional controls on the probability of intrusion and recommended an approach to IHI at the NNSS. A review of Crowe et al. (2007) by the Low-Level Waste Disposal Facility Federal Review Group (DOE 2019) concluded that the recommended approach to IHI was appropriate, but that the probability of IHI, and specifically intrusion involving agriculture, required greater justification. This report updates Crowe et al. (2007) and develops a more comprehensive and up-to-date assessment and justification of the probability of IHI at the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs).

This paper proposes a risk-informed approach to IHI at the NNSS. Appling risk-informed decision-making to an IHI based waste classification decision requires consideration of both the probability and consequences of intrusion. While methods of assessing the consequences of IHI are well established, assessing the probability of intrusion is more problematic. Quantitative assessment of the probability of intrusion is not widely accepted as feasible (NRC 1995, International Commission on Radiological Protection [ICRP] 1998). Furthermore, stakeholder perception of IHI risk is not readily available. Although conventional risk-informed decision-making approaches may not be possible, the probability of IHI scenarios can inform selection and application of appropriate IHI scenarios.

1.1 Inadvertent Human Intrusion

DOE Manual 435.1-1 requires, "*that for purposes of establishing limits on the concentration of radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts calculated for a hypothetical person assumed to inadvertently intrude for a temporary period into the low-level waste disposal facility* (DOE 2011)." While no universal definition of IHI exists, review of IHI analyses across national and international radioactive waste management programs indicates the intruders consistently meet four criteria:

1. The intruder has no knowledge of the hazardous nature of the disposal site. The intruder takes no action to avoid exposure to contamination (DOE 2017).
2. The intruder disrupts the natural or engineered barriers, near-field contamination, or waste, and causes a release of contamination to the accessible environment (International Atomic Energy Administration [IAEA] 2011).
3. Intrusion scenarios should reflect current technologies and conditions near the site. Excessive speculation about future conditions or human activities should be avoided. Stylized drilling and construction excavation scenarios are consistently recommended as activities to be considered for near-surface waste disposal (DOE 2017).
4. Intruder analysis is most appropriately used for optimization of facility design and for setting waste acceptance criteria, rather than as regulatory limits for compliance evaluation (DOE 2017).

These criteria exclude individuals intentionally intruding into waste for any reason. Intruders physically alter the disposal facility either by exhuming contamination including waste or disrupting disposal facility barriers. The definition excludes individuals that simply enter the site without disturbing the facility or redistributing contamination or waste.

Assessing the potential for intrusion should focus on events that would involving drilling or excavation at the disposal facility. Events where drilling or excavation are likely would include residential, industrial, or irrigation based agricultural development at the site. Relevant intrusion events should be identified based on past and current land uses on the NNSS and similar surrounding land. Speculation about future trends and technologies should be avoided.

1.2 Factors Influencing the Probability of IHI

Factors influencing past and current land use are assumed to affect the probability of future IHI. Attractive features, including water, mineral, and agricultural resources, drives most development in southern Nevada.

Subject matter experts (SMEs) evaluating the probability of intrusion at the Area 3 and Area 5 RWMSs proposed that development of communities near the RWMSs would drive residential development in Frenchman and Yucca Flats. Employment opportunities, amenities, and infrastructure in nearby communities would support residential development in surrounding rural unincorporated areas. Intrusion at the RWMSs under these scenarios is assumed to be a random event. Attractive features near the RWMSs may drive the probability of this type of intrusion scenario.

Deterrents to IHI include features making land unsuitable for development and institutional controls. Features potentially deterring development include subsidence craters, steep, rocky, or unstable slopes, ephemeral streams, and playa sediments prone to flooding. Institutional controls have temporal limits and will eventually be less than 100% effective. The use of institutional controls requires an assessment of their effectiveness and durability.

2.0 Attractive Resources

The probability of IHI can be reduced by siting LLW disposal facilities in regions with few attractive resources. Resources attracting residents to southern Nevada in the past include surface water or near-surface groundwater, mineral resources, and the potential to cultivate or gather plant and animal resources. Among these, surface water is key in the arid deserts of southern Nevada where most long-term communities are associated with surface water. No permanent surface water or any other significant attractive resource occurs at or near the Area 3 and Area 5 RWMSs.

2.1 Water Resources

2.1.1 Surface Water and Wetlands

Natural surface water and wetlands are rare on the NNSS and when they occur have very low flows, usually less than 5 liters per minute (L min^{-1}), and cover limited areas (Hall and Perry 2019, US Department of Energy, National Nuclear Security Administration, Nevada Field Office [NNSA/NFO] 2019a). Surface water and wetlands found on the NNSS include 16 springs, 12 seeps, 14 tanks (natural rock basins), and three ephemeral ponds (Hansen et al. 1997, NNSA/NFO 2019a). At least 11 springs and seeps flow year-round (Hansen et al. 1997). Water flowing from NNSS springs and seeps typically flow a short distance before evaporating or infiltrating into the soil. No permanent water sources occur near the Area 3 or Area 5 RWMSs. In addition to permanent surface water, ephemeral pools of water accumulate intermittently on Yucca Flat and Frenchman Flat playas after heavy precipitation events and evaporate in a few hours or weeks depending on conditions (Patton et al. 1986).

Fourteen natural sources of surface water occur within 20 kilometers (km) of the Area 3 and Area 5 RWMSs (Table 2.1). Not all the sources are of sufficient quantity and quality to support a human resident or have evidence of sustaining human settlement in the past. Water sources that have not supported human residence in the past are assumed to be unlikely sites of future development. The springs or seeps in Table 2.1 originate from perched aquifers and are not hydraulically connected to the aquifers below the RWMSs or to any aquifers contaminated by nuclear testing. None of these surface waters are known to be radiologically contaminated.

Table 2.1 Surface Water and Wetlands within 20 km of the Area 3 and Area 5 RWMSs

Name	NNSS Area	Distance to RWMS (km)		Evidence of Supporting Human Residence	UTM† Coordinates	
		Area 3	Area 5		Easting (m)	Northing (m)
Cane Spring	5	28.2	14.2	Yes	580,750	4,072,641
Captain Jack Spring	12	18.5	39.0	Yes	573,834	4,113,579
Coyote Spring	27	33.8	16.2	No	583,594	4,066,568
Pavits Spring	27	32.4	16.1	No	581,931	4,068,118
Reitmann Seep	7	7.1	26.0	No	591,278	4,105,578
Tippipah Spring	16	15.8	30.0	Yes	570,857	4,099,671
Tongue Wash Tank	12	19.9	39.9	No	571,360	4,113,050
Tupapa Seep	27	34.1	17.2	No	582,129	4,066,459
Wahmonie Seeps 1, 2, 3, 4	26	27.8	16.5	No	577,679	4,073,923
White Rock Spring	12	19.6	41.0	Yes	577,019	4,117,282
Yucca Playa Pond	6	9.8	13.8	No	584,805	4,090,584

† - Universal Transverse Mercator

Figure 2.1 Surface Water and Wetlands within 20 km of the Area 3 RWMS

The water source closest to the Area 3 RWMS is Reitman Seep, 7 km to the northeast (Figure 2.1). Reitman Seep flows year-round, but flows are low, less than 1 L min^{-1} (Hansen et al. 1997). There is no evidence of human residence at this site, but a basin or livestock guzzler constructed from a 55-gallon steel drum is present (Hansen et al. 1997).

Tippipah Spring, 16 km west of the Area 3 RWMS, is the closest spring with evidence of human residence. Hansen et al. (1997) report a maximum flow of 2.7 L min^{-1}. The site has remnants of a cabin, corral, and water tanks, suggesting past use for livestock grazing or wild horse capture (Hansen et al. 1997).

Approximately 20 km northwest of the Area 3 RWMS, there is a cluster of springs, seeps, and tanks at the base of Rainier Mesa that have a long history of supporting small communities. Centered at White Rock Spring and including nearby Captain Jack Spring, Tongue Wash Tank, and several more springs to the northeast, this cluster of springs has supported Native American and Euro-American communities in the past. This area below Rainier Mesa is, perhaps, one of the more likely sites for community development near the Area 3 RWMS.

The surface water closest to the Area 5 RWMS is Yucca Pond, an ephemeral pool 14 km to the northwest (Figure 2.2). Yucca Pond has no evidence of past human residence.

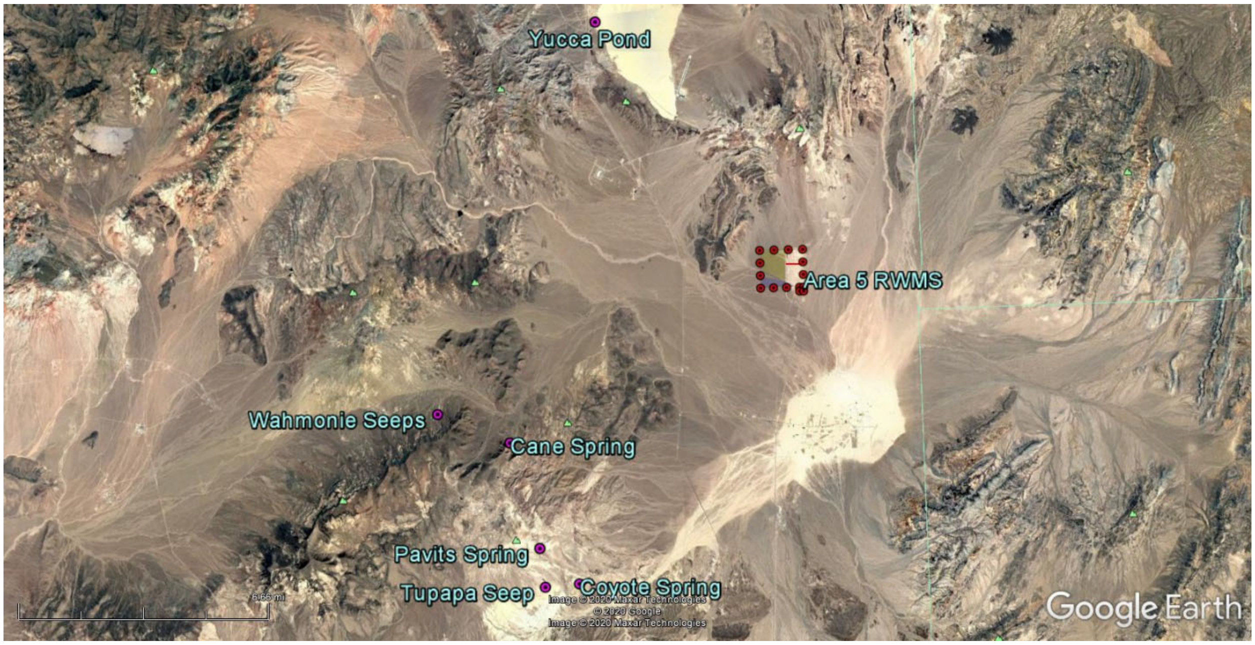


Figure 2.2 Surface Water and Wetlands within 20 km of the Area 5 RWMS

The permanent surface water source closest to the Area 5 RWMS with evidence of human residence is Cane Spring, approximately 14 km southwest of the site. Cane Spring is one of the highest yield natural springs on the NNSS with a long history of human residence. Limited flow rate measurements suggest variable and low flows, typically less than a few liters per minute (Hansen et al. 1997).

Two small intermittent springs (Coyote Spring and Pavits Spring) and an intermittent seep (Tupapa Seep) occur on the eastern slope of Hampel Hill, approximately 15 to 16 km southwest of the Area 5 RWMS. There is no evidence of human occupation at these sites. While the intermittent Wahmonie seeps occur near the abandoned Wahmonie mining camp, there is no evidence that they were ever used as a water source.

In addition to natural sources of water, human activity on the NNSS has created permanent and ephemeral sources of surface water that will persist near the Area 3 and Area 5 RWMSs after loss of institutional control. Depressions created by human activity including nuclear testing subsidence craters and excavations on the Yucca and Frenchman Flat playas, which will collect run-off as long as they persist. At least 12 man-made depressions occur on Frenchman Flat playa (Hall and Perry 2019). Like most ephemeral water sources on the NNSS, depressions are unlikely to hold water frequently enough or long enough to support human settlement.

A permanent source of anthropogenic surface water near the Area 3 RWMS is effluent draining from E-Tunnel (U12e) in Rainier Mesa, approximately 21 km northwest of the Area 3 RWMS near White Rock Spring. The effluent drains a perched aquifer and flows into a series of small retention basins constructed in an ephemeral wash. Past attempts to block the flow have failed due to rock fractures and drainage is expected to continue in the future. In 1996, the flow was reported to be 19 to 38 L min^{-1} (Huckins-Gang and Townsend 2009), making it probably the most productive spring on the NNSS.

Beyond the boundaries of the NNSS, sites with permanent surface water that could support communities include Oasis Valley, Ash Meadows, and Pahranagat Valley. The closest off-site sources of permanent surface water are Oasis Valley, 60 km west of the Area 3 RWMS, and Ash Meadows, 67 km southwest of the Area 5 RWMS.

Surface water is not an attractive resource at the Area 3 and Area 5 RWMSs. Small springs occur more than 10 to 20 km from the RWMSs, but the flows are low and variable. Residents at those sites might utilize the RWMSs for cattle grazing or recreation, but these activities do not disrupt buried waste and are not within the scope of IHI. In the context of IHI, surface water is not an attractive resource that could cause intrusion at the RWMSs.

2.1.2 Groundwater

Communities occur in southern Nevada where groundwater resources are available. Groundwater is the only permanently available source of water at the Area 3 and Area 5 RWMSs. The uppermost aquifers at both sites have sufficient yield and quality to be sources of drinking water. A deeper, laterally extensive, regional carbonate aquifer underlays Yucca and Frenchman Flat (Fenelon et al. 2010). The depth to groundwater is at least 236 meters (m) at the Area 5 RWMS and is approximately 492 m deep at the Area 3 RWMS. The carbonate aquifer occurs approximately 860 m below the Area 3 RWMS and 1,300 m below the Area 5 RWMS (Shott et al. 1998, 2001).

Water wells in southern Nevada are significantly shallower than the aquifers beneath the Area 3 and Area 5 RWMSs. The Nevada Division of Water Resources (NDWR) maintains an online database recording the depth to water for 26,910 water wells in Clark, Nye, and Lincoln Counties (NDWR 2020). The mean depth of household and irrigation water wells is 27 and 19 m, respectively (Table 2.2). Industrial and water supply wells are deeper, with mean depths of 59 and 60 m respectively.

Table 2.2 Summary Statistics of Groundwater Wells in Clark, Nye and Lincoln Counties, Nevada Recorded in the NDWR Data Base (from NDWR 2020)

Statistic	Well Use			
	Household Water Supply	Industrial	Irrigation	Public Water Supply
Number	22,518	231	1,698	2,463
Mean Depth (m)	27.1	58.5	18.7	60.0
Maximum Depth (m)	350	370	248	764
P(Well Depth > 236 m†)	0.00036	0.0043	0.0012	0.0024
P(Well Depth > 492 m‡)	< 0.00004	< 0.004	< 0.0006	0.00041

† - Depth of Area 5 RWMS uppermost aquifer
‡ - Depth of Area 3 RWMS uppermost aquifer

The probability of a water well exceeding the depth of the uppermost aquifers at the RWMSs can be assessed using a frequentist approach, where the probability is estimated as the number of wells exceeding the aquifer depth divided by the total number of wells in the NDWR online data base (NDWR 2020). Using this approach, the probability of a water well reaching the depth of the Area 3 RWMS aquifer is extremely low, and without precedent for household water supply, industrial, or irrigation wells. A single public water supply well, one in 26,910 wells in Clark, Nye, and Lincoln Counties, is deep enough to reach the Area 3 RWMS uppermost aquifer. The probability of a household water supply well deep enough to reach the Area 3 uppermost aquifer is less than 0.00004 based on current conditions. Wells reaching the upper carbonate aquifer are even less likely. The probability of residential, industrial or irrigation based agricultural development at the Area 3 RMWS appears negligible considering current conditions in southern Nevada.

Given the current use of groundwater resources in southern Nevada, the probability of a water well at the Area 5 RWMS is also low. An industrial well has the highest probability, 0.4%, of reaching the uppermost aquifer at 236 m. A residence with a groundwater well is the least likely scenario with a probability of 0.0004. Development at the Area 5 RWMS based on a local water supply well appears unlikely, but is slightly more probable than at the Area 3 RWMS.

Groundwater resources capable of supporting residential, industrial, or agricultural development exist at the Area 3 and Area 5 RWMSs. A water well reaching the uppermost aquifer at the Area 3 RWMS would be deeper than 99.9% of water withdrawal wells in Clark, Lincoln, and Nye Counties. A water well at the Area 5 RWMS would be deeper than 99% of wells. Development at the RWMSs driven by groundwater availability is unlikely.

2.2 Geological Resources

Development can occur in southern Nevada at remote locations with minimal or no water resources when economically significant geological resources are present. The Area 3 and Area 5 RWMSs sit upon alluvial fans formed from thick deposits of unconsolidated alluvium. Among 23 mining districts known in southern Nye County, no mineral deposits occur in unconsolidated alluvium (Gustafson et al. 1993).

2.2.1 Sand and Gravel Resources

The unconsolidated alluvial deposits at the Area 3 and Area 5 RWMSs are a potential source of sand and gravel for construction or industrial use. There is little precedent, however, for considering gravel mining as an intrusion event at LLW disposal facilities. Presumably, an intruder seeking sand and gravel would move to a different location upon encountering waste.

The Area 3 or Area 5 RWMS sand and gravel resources may attract intruders if they are in demand and of sufficient quality. Unconsolidated alluvium is ubiquitous throughout the valleys of southern Nevada. The quality and properties of alluvium at the sites is not exceptional or unique. Sand and gravel are typically mined near the point of use. Most sand and gravel mined in Nevada is extracted within Las Vegas where there is a strong demand (Bureau of Land Management [BLM] 2013). Sand and gravel are not attractive resources that would affect the probability of IHI at the Area 3 and Area 5 RWMSs.

2.2.2 Petroleum Resources

Drilling intrusion may occur because of petroleum exploration or production. Geologic targets for petroleum resources occur in central and eastern Nevada, but most potential petroleum traps in Nevada have a long and complex history of deformation that makes it unlikely that oil is still present. Oil exploration in Nevada is considered high risk due to the low probability of success.

Oil exploration began in Nevada in 1907, but the first productive fields were not discovered until 1954 in Railroad Valley approximately 150 km northeast of the RWMSs (Garside et al. 1988). The only fields outside Railroad Valley were discovered approximately 400 km north in Pine Valley in Eureka County in 1982. Significant commercial natural gas production does not occur in Nevada. Nationally, Nevada is a minor petroleum producer with production in decline since the mid-1990s.

Oil exploration and production wells in Nevada are much less common than water wells. Oil well permitting did not begin until 1953, when the NNSS was already withdrawn from public access. A review of 67 known pre-1953 wells identified no exploration wells in Nye County, which includes the NNSS, and Lincoln County (Linz 1957). Exploration wells drilled from 1954 to 1996 in Nye and Lincoln Counties near the NNSS were dry (Garside et al. 1988, Hess and Johnson 1996). Parts of Clark County have slightly higher potential for petroleum reserves. Exploratory wells in Clark County have had hydrocarbon shows, but no oil fields have been discovered. Most of the NNSS, including Yucca Flat and Frenchman Flat, has a low potential for petroleum resources (NBMG 2020a). Drilling intrusion due to petroleum exploration or production is unlikely and probably negligible compared to the probability of water well drilling.

2.2.3 Mineral Resources

The potential for mineral resources in the unconsolidated alluvial deposits at the Area 3 and Area 5 RWMSs is very low. Six mining districts are known within the NNSS (NBMG 2020b). None of the districts are known to have any significant economic potential, but have not been evaluated since the 1940s.

Four mining districts occur near the Area 3 RWMS: Mine Mountain, Rainstorm, White Rock Spring, and Oak Spring Districts. The closest district is Mine Mountain, approximately 12 km to the west-southwest. Mine Mountain District produced limited quantities of mercury, lead, and silver in 1928 and is thought to have no economically significant reserves remaining (Richard-Haggard 1983). The most economically significant district near the Area 3 RWMS is the Oak Spring District approximately 23 km to the north. The Oak Spring District has produced multiple metals and minerals including tungsten, gold, silver, copper, turquoise, lead, antimony, and molybdenum. Known tungsten deposits at the Oak Spring District were estimated to have a value of approximately $43,000 in 1983 (Richard-Haggard 1983).

The Rainstorm and White Rock Spring Districts are reported to contain zeolites. Zeolites are a group of open structure aluminosilicate minerals used as absorbents and catalysts. Most zeolites used in industry are synthetic. Zeolites are common in altered volcanic tough deposits found throughout the western US. The economic viability of zeolite claims on the NNSS is unknown.

The mining districts closest to the Area 5 RWMS are the Wahmonie District, 21 km to the west, and the Mine Mountain District 23 km the northwest. The Wahmonie District briefly produced very limited quantities of gold in 1928 (Kral 1951). Both districts are reported to have negligible reserves remaining (Richard-Haggard 1983).

Drilling or excavation at the Area 3 and Area 5 RWMSs for mineral exploration is unlikely as mineral resources rarely occur in alluvium in southern Nevada. Economically significant mineral resources are not known to occur near the RWMSs.

2.3 Agricultural Resources

An arid climate and infertile soils severely limit commercial agriculture in southern Nevada. Residents of Clark, Nye, and Lincoln counties use 1% or less of the land area for commercial agriculture (Table 2.3). The most common commercial agricultural activities are grazing of livestock and production of hay for livestock. Cattle are the most common livestock raised. Forage, mostly alfalfa, accounts for greater than 98% of the cultivated cropland in Clark and Nye counties. In Lincoln County, farmers produce mostly forage (87%) with the remaining land used predominantly for feed corn. Hay crops grown in southern Nevada require irrigation. Unirrigated farmland is mostly rangeland used to graze cattle.

Table 2.3 Summary Statistics of Land in Agriculture in Southern Nevada Based on 2017 Census Data (USDA 2019)

Statistic	County		
	Clark	Nye	Lincoln
Land used as farms (% of area)	0.3†	0.8	1
Cropland (% of farmland)	D	24	31
Irrigated farmland (% of farmland)	24	24	37
Top Crop Type (by land area)	Forage	Forage	Forage
Top Crop Area (% of cropland)	100	98	87

† - 2012 census data, 2017 data reported as D
D – Data withheld due to small number of farms reporting

The NNSS has no history of commercially viable agricultural use (Richard-Haggard 1983). Native Americans cultivated maize, squash, beans, and other indigenous plants at several springs on the NNSS (Stoffle et al. 1990). Remnants of corrals and livestock guzzlers at several springs on the NNSS are evidence of past livestock grazing or wild horse capture (Fehner and Gosling 2000, NNSA/NFO 2019a).

Cattle grazing is the most common agricultural use of land in southern Nevada. The NNSS has land suitable for cattle grazing with an average carrying capacity of 0.02 animal unit months per hectare (AUM ha^{-1}) (Richard-Haggard 1983). The Area 3 RWMS is within a Transitional Desert *Grayia-Lycium* community with an estimated carrying capacity of 0.033 AUM ha^{-1} (Richard-Haggard 1983). The Area 5 RWMS is surround by a Mojave Desert *Larrea* community with a slightly higher carrying capacity of 0.046 AUM ha^{-1} (Richard-Haggard 1983). Commercial cattle ranching was attempted on the NNSS in the early part of the 20th century by the Clay Spring Cattle Company and its successor the Naquinta Cattle Company, but both efforts were economic failures due to the limited quantity and quality of forage (NNSA/NFO 2019a).

The US Environmental Protection Agency operated an Experimental Farm and maintained a dairy cattle herd in Area 15 on Yucca Flat from 1957 to 1981. The Experimental Farm conducted scientific research on uptake of fallout radionuclides (Smith and Black 1984, Black and Smith 1984). The Experimental Farm demonstrates that cattle ranching and cultivation of irrigated hay crops are technically feasible on the NNSS, but their economic viability is doubtful.

Production of irrigated alfalfa is the most likely cropland use of the NNSS based on current agriculture in southern Nevada. Irrigable soils occur in the alluvium-filled valleys of the NNSS, but all have some degree of limitation (Richard-Haggard 1983). Soils at the Area 3 RWMS have limitations due to moderate water holding capacity (Richard-Haggard 1983). The Area 5 RWMS has soils with severe limitations due to low water holding capacity (Richard-Haggard 1983). The BLM has assessed the agricultural potential of the NNSS considering multiple factors including land quality and water availability. The BLM found land surrounding the Area 3 RWMS to be unsuitable for irrigation agriculture (Richard-Haggard 1983). The Area 5 RWMS is located on land deemed suitable for irrigation agriculture by BLM, but less than 5% of irrigable land in Nevada is in use (Richard-Haggard 1983). The shallower depth of groundwater at the Area 5 RWMS is probably a factor increasing its suitability for irrigation relative to the Area 3 RWMS. The cost of obtaining deep groundwater at the Area 5 RWMS is likely to remain a significant deterrent to irrigation agriculture.

The NNSS has few agricultural resources that are likely to attract commercial farmers or ranchers. Cattle grazing is the most likely commercial agricultural activity. Past commercial attempts to graze cattle on the NNSS were short-lived and ultimately unsuccessful. The depth to groundwater at the RWMSs makes production of irrigated hay crops extremely unlikely.

2.4 Recreational Resources

Public land in Nevada is used for multiple recreational purposes including camping, hiking, horseback riding, off-road vehicle driving, and hunting. Recreational activities may expose members of the public to contamination released from the site, but most are not intrusion events as they do not release contamination or disrupt barriers.

Off-road vehicle use may be a recreational activity with some intrusion-like characteristics. Off-road vehicle traffic may degrade cover performance by increasing erosion and damaging vegetation. Drilling and construction excavation intrusion events, however, are expected to have much higher consequences, because they involve direct exposure to waste and much longer exposure times.

Most recreational activities are not intrusion events because they do not disrupt natural or engineered barriers, near-field contamination, waste, or cause a direct release of contamination to the accessible environment. The consequences of recreational activities are likely bound by drilling or construction scenarios.

3.0 Land Use

Current and past land use are indicators of potential future uses. The NNSS is located within one of the most sparsely populated regions of the US. Nye County, Nevada, has a population density of 0.93 persons per square kilometer (km^2) compared to a US average of 14 persons per km^2 in unincorporated areas (US Census Bureau [USCB] 2020).

3.1 Past Land Use

3.1.1 Prehistoric Land Use

Native Americans have lived on the NNSS for approximately 12,000 years (Stoffle 2001). Population densities have fluctuated over time with changing climatic conditions and cultural adaptations. More than 8,000 years ago, the Great Basin climate was colder and wetter than current conditions. Pluvial lakes and marshes formed throughout the Great Basin, supporting larger populations of Native Americans (Fehner and Gosling 2000). Pluvial lakes appear to have been absent on the NNSS during this period. The absence of lakes and rarity of artifacts from this period suggests that Native American populations were sparse on the NNSS (NNSA/NFO 2019a). Populations waned throughout the Great Basin 8,000 to 4,500 years ago as the climate became hotter, more arid, and drought frequency increased (Fehner and Gosling 2000). Since then, the climate has continued to oscillate between cold/wet and hot/dry conditions. After 4,500 years ago, populations appear to have increased as the climate became less arid and the diversity of food resources exploited by Native Americans increased (NNSA/NFO 2019a).

3.1.2 Historical Land Use

Migrant observations of Native Americans living on the NNSS begin to appear during the 1840s. Early migrants referred to the entire region between Pahranagat Valley and the Sierra Nevadas as “Death Valley” due to the lack of surface water and grass (Fehner and Gosling 2000). Native Americans outnumbered Europeans on the NNSS until 1900 and continued to use the NNSS until the 1940s when large tracts of land were withdrawn for military purposes (Stoffle et al. 1990). Euro-American settlement of the NNSS has been sparse and short-lived due to a lack of water resources and economically significant mineral or agricultural resources.

At the time of European contact, the NNSS was occupied by the Southern Paiute and Western Shoshone (Stoffle 2001). Three groups were known to use the NNSS in the recent past (Stoffle et al. 1990). The Western Shoshone *Ogwe’pi* people resided in Oasis Valley where Beatty is now located. The Western Shoshone *Eso* people’s core residence was the Rainier Mesa area on the northwest fringe of Yucca Flat. A mixed group of Western Shoshone and Southern Paiute formed the *Toi’ oits* group at the Ash Meadows oasis in the Amargosa Valley south of the NNSS. Members of this group also resided at Cane Spring on the NNSS.

Members of these three groups established smaller villages and family residences on the NNSS at oases and springs (Stoffle et al. 1990). Residents of these sites ranged over a large area, migrating seasonally along elevation gradients, in response to weather conditions and resource availability (Stoffle et al. 1990, NNSA/NFO 2019a).

The site closest to the Area 3 RWMS with evidence of human residence is Tippipah Spring, approximately 16 km west of the Area 3 RWMS (Stoffle 2001). There is evidence at this site for semi-permanent American Indian habitation with reports of vegetable cultivation (Stoffle et al. 1990, Stoffle 2001). Euro-Americans grazing cattle on the NNSS later occupied the site seasonally (Hansen et al. 1997, Fehner and Gosling 2000).

White Rock Spring and the nearby Captain Jack Spring at the base of Rainier Mesa, approximately 18 – 19 km northwest of the Area 3 RWMS, supported several *Eso* Indian villages with a population of around 40 persons in 1875, a time when Native American populations had been significantly reduced by European contact (Stoffle et al. 1990). American Indians continued to reside at this site into the 1930s. Beginning in 1889, miners seeking gold and silver filed multiple claims in the Oak Spring area, approximately 7 km to the northeast of White Rock Spring (Fehner and Gosling 2000). Mining activity continued in the area into 1941 with multiple claims made for small deposits of copper, lead, silver, gold, turquoise, and tungsten (McLane 1996).

The site closest to the Area 5 RWMS with evidence of semi-permanent residence is Cane Spring, approximately 14 km to the southwest. Emigrates passing Cane Spring in 1849 found evidence of Native Americans cultivating maize and squash (Stoffle et al. 1990). Lithic artifacts at the site indicate a long period of Native American occupation (Johnson et al. 2000). A cabin and corral at the site supported a stage stop in the late 1800s (Stoffle et al. 1990). A reservoir constructed at the site is reported to have been used by Euro-Americans grazing cattle (Hansen at al. 1997). In 1928, Cane Spring supplied water via a pipeline to the Wahmonie Mining Camp, approximately 3 km west-northwest.

Past habitation patterns suggest the probability and character of future use. There is no evidence of past human residence in valley bottoms of Yucca Flat and Frenchman Flat, suggesting that residential development at the RWMSs is unlikely. Past settlement on the NNSS has been limited to small communities, family groups, or individuals at a few sites with permanent surface water.

3.2 Current Land Use

3.2.1 NNSS Land Use

The NNSS is used by the DOE/NNSA, the Department of Defense (DoD) and other Federal agencies for experiments, training, and research related to national security/defense, environmental management, and non-defense research and testing. Primary National security/defense related activities include nuclear weapon Stockpile Stewardship and Management, Nuclear Emergency Response, and Nonproliferation and Counterterrorism experimentation. Primary environmental management activities include nuclear and hazardous waste management and environmental restoration.

3.2.2 Off-Site Land Use

Most land adjacent to the NNSS is undeveloped land owned by the Federal Government. The NNSS is located within Nye County, Nevada. Multiple Federal agencies including the BLM, DoD, DOE, and the US Fish and Wildlife Service control 93% of the land within Nye County (NNSA/NSO 2013). Approximately 22% of the land in Nye County is restricted access federally controlled land (NNSA/NSO 2013). A 6,538 km^2 protected wildlife range, the Desert Wildlife National Refuge (DWNR), and a 11,816 km^2 military gunnery range, the Nevada Test and Training Range (NTTR) immediately surround the eastern, northern, and western boundaries of the NNSS (USAF 2017) (Figure 3.1).

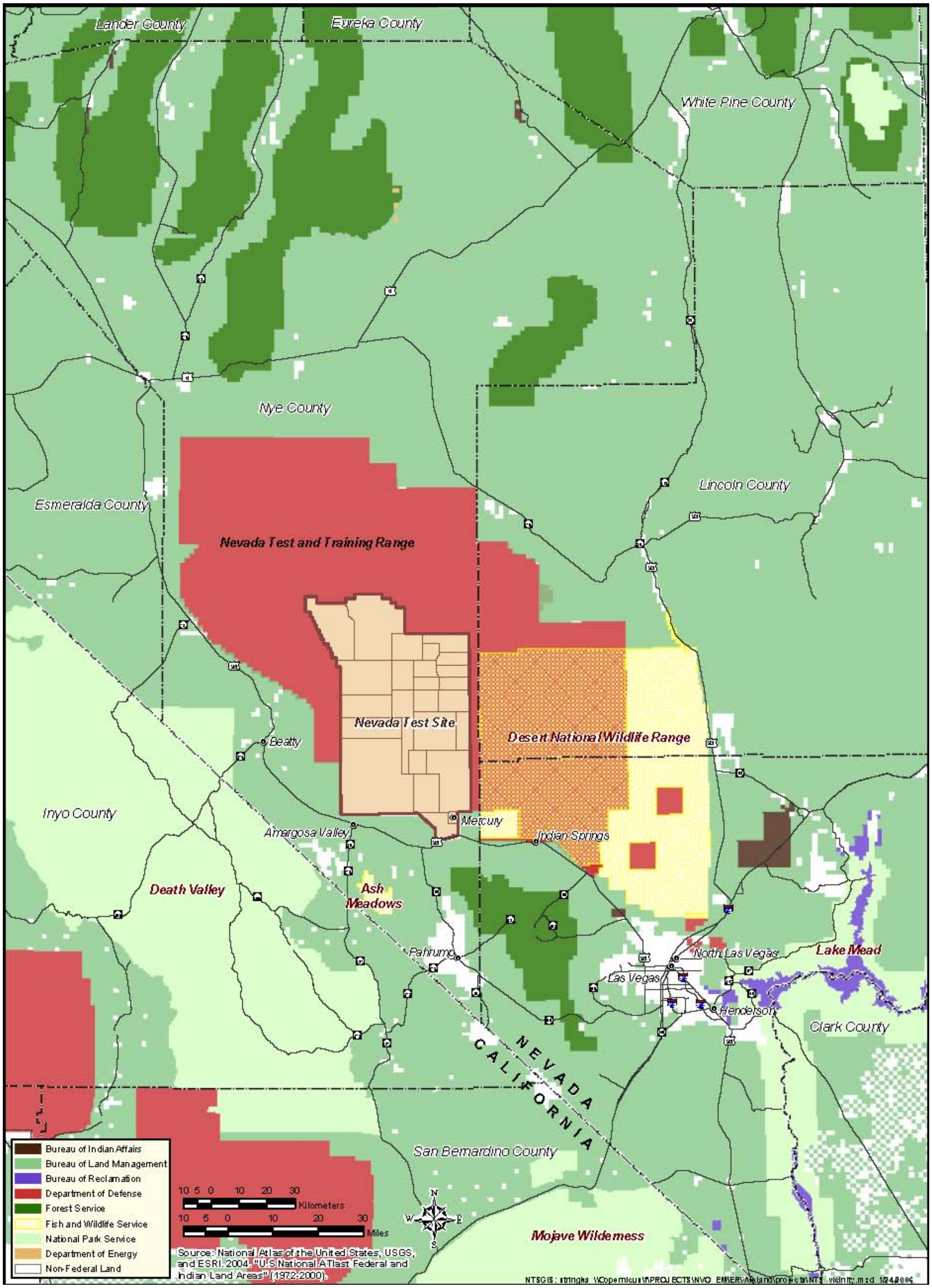


Figure 3.1 Land Ownership and Use Adjacent to the NNSS

BLM land, and portions of the DWNR not within the NTTR, are open to recreational use. BLM land may also be leased for solar energy production, oil and gas exploration and production, mining, and grazing. Northern portions of the NTTR have been used for grazing in the past, but are currently closed to all public use (USAF 2017). Mining has occurred on the NTTR prior to military withdrawal in the 1940s, but recent surveys indicate that no economically viable precious or base metals deposits are known (USAF 2017).

Primary land-uses on adjacent non-governmental lands include urban and rural communities, mining, grazing, agriculture, and recreation (NNSA/NSO 2013).

4.0 Institutional Controls

DOE has a formal policy to use institutional controls to prevent or limit IHI and environmental exposure to residual contaminants and other hazards (DOE 2015a). DOE has committed to maintain institutional controls as long as they are necessary for their intended purpose (DOE 2015b).

4.1 Institutional Control Policy and Guidance

DOE institutional controls are essential components of a defense-in-depth strategy that uses multiple, relatively independent layers of safety to protect human health and the environment (DOE 2015a). Institutional controls may include administrative or legal controls, physical barriers or markers, and methods to preserve information and data and inform current and future generations of hazards and risks. It is DOE's policy to maintain the institutional controls as long as necessary to perform their intended protective purposes and seek sufficient funds (DOE 2015a). Transfer of real property requires that there is a reasonable expectation that all necessary institutional controls can be maintained after the transfer and the new owner, whether a DOE or non-DOE entity, understands and is capable of meeting its institutional control responsibilities.

The NNSA/NFO established a formal NNSS institutional control policy in 2008 (NNSA/NSO 2008). The current institutional control policy (NNSA/NFO 2019b) is to "*implement, maintain, and enforce institutional controls that restrict access to, and use of, the NNSS and to ensure the continuity of appropriate institutional controls in the future.*" Should the NNSS be determined to have no further mission (closed), the DOE Office of Legacy Management will ensure the continuity of the appropriate institutional controls.

4.1.1 NNSS Site-Wide Institutional Controls

Administrative, informational, and physical NNSS institutional controls protect the Area 3 and Area 5 RWMSs. The NNSS national security mission ensures the site will be subject to physical security and surveillance as long as the mission continues. The RWMSs are within the NNSS on federally owned land transferred to DOE/NNSA and withdrawn from public use. The Area 5 RWMS in within the Area 5 Radioactive Waste Management Complex (RWMC). The BLM permanently transferred the Area 5 RWMC to the DOE/NNSA in 2009.

DOE Order 458.1 places criteria on the release of real property. The order requires that property with residual contamination be controlled as long as doses to the public may exceed 0.25 millisievert (DOE 2013). There is no time limit on DOE's responsibility to manage residual contamination.

Initiation of new activities on the NNSS requires a Real Estate Operations Permit (REOP) (NNSA/NFO 2019c). The REOP process ensures that work (1) is well defined and has well-defined geographical boundaries; (2) has identified the hazards and has established and implemented controls to mitigate those hazards; (3) is protective of the environment (e.g., includes archaeological survey requirements, land-disturbance minimization, and waste management); (4) is properly authorized; and (5) is managed effectively. The REOP process ensures that institutional controls are enforced as long as the NNSS mission continues.

Public knowledge is a type of passive institutional control. The existence of radiological contamination on the NNSS is likely to remain in the public knowledge for considerable time due to the historic nature of activities on the NNSS. The hundreds of craters formed at the NNSS by nuclear testing are likely to persist for more than 1,000 years and act as markers warning of radiological contamination. Federal Facility Agreement and Consent Order (FFACO) URs are another source of information in the public domain.

4.1.2 NNSS Federal Facility Agreement and Consent Order Institutional Controls

The FFACO, signed in 1996, is a legally binding agreement among the NNSA/NFO, DoD, and state of Nevada, which establishes a process for identifying, characterizing, and providing corrective actions for historical sites within the state of Nevada related to the development, testing, and production of nuclear weapons (FFACO 1996). The corrective action strategy follows a four-step process: (1) identify the corrective action sites (CASs), (2) group the CASs into corrective action units (CAUs), (3) prioritize the CAUs for funding and work, and (4) implement corrective action investigation and/or corrective actions, as applicable.

FFACO CASs may be subject to institutional controls in the form of use restrictions (URs). FFACO URs are established at CASs when contamination left in place exceeds final action levels based on the site-specific exposure scenario. FFACO URs require that warning signs be posted on the site boundary, periodic inspections be performed, and, potentially, barriers and monuments be established. CASs with radioactive contamination may require DOE radiological postings. FFACO URs are documented on a standardized UR form, which includes an aerial photograph showing the UR boundary and coordinates. The UR data are included in the FFACO data set and recorded in a geographic information system database maintained by the NNSS Management and Operating contractor.

Administrative URs may be established at CASs with contamination that does not exceed final action levels but where a potential exists for future workers to receive a dose exceeding action levels. The purpose of administrative URs is to ensure that higher hazard land uses are not inadvertently implemented within the CAS. Administrative URs do not require posting, periodic inspections, or barriers.

FFACO CASs for Underground Testing Areas (UGTAs) also have UR boundaries enclosing groundwater contamination that exceeds action levels. UGTA UR boundaries enclose groundwater contamination that may exceed drinking water maximum contaminant levels within 1,000 years. The UR boundaries are negotiated with the State of Nevada. The DOE, BLM, and DoD have committed to maintain FFACO UR records for as long as the land is under their jurisdiction. FFACO UGTA URs are assumed to remain effective for 1,000 years in the Area 3 and Area 5 RWMSs composite analyses.

The state of Nevada, NDWR, maintains governmental control over all groundwater resources. The NDWR manages appropriation and reallocation of the public waters through a permitting process. NNSA/NFO consults NDWR annually to verify that no new permit applications for water use have been granted in basins within FFACO UR boundaries. If permits have been issued, an evaluation will be performed to verify that UR boundaries remain protective.

4.2 Area 3 RMWS Institutional Controls

The Area 3 RWMS is subject to multiple institutional controls, including five FFACO UR boundaries (Table 4.1). Three UR boundaries enclose surface soil contamination from aboveground testing and one boundary encloses the U-3ax/bl mixed waste disposal cell. The CAU 97, Yucca Flat UGTA, URs and UR boundary remain to be negotiated with the state of Nevada. The Area 3 RWMS is expected to be within the CAU 97 UR boundary. After closure, UGTA CAUs typically have URs that prohibit any sub-surface activity including drilling, pumping, and testing of wells without NNSA/NFO approval.

Table 4.1 FFACO CASs within the Area 3 RWMS with FFACO URs or Administrative URs

CAU	CAS	Name	Category	Institutional Controls/Use Restriction
97	720 Underground Test CASs	Yucca Flat	UGTA	To be determined
110	03-23-04	U-3ax/bl Crater	Industrial Site	Fencing, signs, inspections and maintenance, activities altering containment prohibited
569	03-23-13	T-3T Contamination Area	Soil Site	Signs, inspections, activities altering containment prohibited
	03-23-15	S-3G Contamination Area	Soil Site	Signs, inspections, activities altering containment prohibited
	03-23-09	T-3 Contamination Area	Soil Site	Activities altering containment prohibited

The DOE Order 435.1 closure plan (NSTec 2007) specifies multiple institutional controls at the Area 3 RWMS including fences, signs, and monuments with 30 years of inspection and active maintenance of the cover, barriers, and postings.

4.3 Area 5 RMWC Institutional Controls

The Area 5 RWMC includes six FFACO UR boundaries. The CAU 111 UR boundaries enclose three areas with mixed waste disposal cells in the 92-acre Low-Level Waste Management Unit. The CAU 577 UR boundary corresponds with individual disposal cells containing Resource Conservation and Recovery Act-regulated waste in the Northern Expansion Area (Table 4.2). The CAU 577 URs are to be determined, but expected to be similar to CAU 111.

Table 4.2 FFACO CASs within the Area 5 RWMS with FFACO URs or Administrative URs

CAU	CAS	Name	Category	Institutional Controls/Use Restriction
111	05-21-01	Mixed Waste Pits	Industrial Site	Fencing, signs, quarterly inspections, activities altering containment prohibited
005	05-16-01	Landfill	Industrial Site	Fencing, signs, inspections and maintenance, activities altering containment prohibited
577	05-21-02	Waste Disposal Cell 12	Industrial Site	Fencing, signs, inspections and maintenance, activities altering containment prohibited
	05-21-03	Waste Disposal Cell 15	Industrial Site	
	05-21-04	Waste Disposal Cell 17	Industrial Site	
	05-21-05	Waste Disposal Cell 20	Industrial Site	
	05-21-06	Waste Disposal Cell 21	Industrial Site	

The DOE Order 435.1 closure plan specifies multiple institutional controls at the Area 5 RWMS including fences, signs, inspections, and maintenance (NSTec 2008). URs, comparable to FFACO UGTA URs, are planned for Area 5 RWMS disposal cells closed under DOE Order 435.1.

5.0 Expert Judgement

Events causing IHI at the Area 3 or Area 5 RWMSs, such as residential development, are rare in the arid desert valleys of southern Nevada. Expert judgement, which is a formal process of eliciting the opinions or degree of belief of SMEs, can estimate the probability of rare events or events with uncertainty that additional data collection cannot reduce.

5.1 Probability of Drilling Intrusion

Quantitatively estimates of the probability of intrusion at the Area 3 and Area 5 RWMSs have been prepared using expert judgement (Black et al. 2001, Bechtel Nevada [BN] 2001). This section summarizes the probability of drilling intrusion. The original reports contain the complete details of the elicitation and estimation of the probability of IHI for drilling and construction intrusion (Black et al. 2000, 2001; BN 2001).

Expert judgement, as applied to IHI at the NNSS, followed a five-step process.

Step 1: Develop Preliminary Intrusion Models. The facilitators of the expert judgement initially developed models of intrusion and identified important factors in the analysis. To avoid excessive speculation about future events, the facilitators assumed that intrusion was most likely to occur during development of a homesteader's residence on the RWMS. The facilitators estimated important deterministic inputs including the time period of concern, the area of the RWMS disposal cells, and the habitable areas of Frenchman Flat and Yucca Flat. The facilitators also identified management controls (i.e., institutional controls) potentially deterring intrusion.

Step 2: Stakeholder Review of Preliminary Models and Approach. The preliminary approach and models were presented for review and comment to stakeholder groups including the performance assessment preparation team (i.e., performance assessment modelers, Sandia National Laboratories, Desert Research Institute), state agencies (i.e., Nevada Department of Environmental Protection, Nevada Nuclear Waste Project Office), and public groups (i.e., Community Radiation Monitoring Program, Community Advisory Board, the University of Nevada Las Vegas, Citizen Alert, and Nevada Nuclear Waste Task Force).

Step 3: Convene SMEs. Based on the preliminary models, the facilitators identified necessary subject matter areas and potential SME candidates. The selected SMEs convened and reviewed the preliminary models. The SMEs considered ranching, mining, or irrigation-based agriculture at the RWMSs as unlikely scenarios. The SMEs identified additional residential scenarios driven by nearby community development as more likely than the preliminary single homesteader scenario proposed by the facilitators.

In the SMEs opinion, future residents in Frenchman Flat or Yucca Flat would most likely be members of an outlying residential community dependent on a larger nearby community. Likely locations of supporting communities included Pahrump, Amargosa Valley, Jackass Flats, Mercury, or White Rock Spring. The SMEs identified several plausible industries or organizations supporting the communities including research (e.g., nuclear or solar energy), mining, military bases, prisons, religious groups, or Native American communities. The SMEs identified five management controls affecting the probability of IHI including institutional control (e.g., government access control), site knowledge, placards and markers, surface barriers, and subsurface barriers.

Step 4: SME Elicitation. The elicitation process consisted of three phases: conditioning, structuring, and elicitation. During the conditioning phase, the SMEs reviewed background information, toured the NNSS, and were trained in elicitation techniques. The intrusion models, in the form of influence diagrams, were finalized during the structuring phase. Finally, the elicitation phase produced the quantitative probabilities required by the intrusion models.

Step 5: Estimate Intruder Scenario Probability by Monte Carlo Simulation. Influence diagrams were prepared and iteratively refined during meetings with the SMEs and during the elicitation process. The influence diagrams qualitatively describe the simulation models used to estimate the scenario probabilities. Polygons in the influence diagrams indicate deterministic input to the analysis. Circles represent chance variables. Chance variables without other inputs are probability distributions estimated by the SMEs during the elicitation. The simulation model calculates chance variables with inputs.

The top-level influence diagram indicates how the different scenarios and management controls affect the total modified probability of intrusion (Figure 5.1). The community scenario probability includes probability estimates for three community scenarios: a base community at the RWMSs (local community scenario), a community of commuters working in an expanded Las Vegas metropolitan area (expanded Las Vegas scenario), and a community of commuters working at a site near the RWMSs, such as Jackass Flats or Mercury (Jackass Flats scenario).

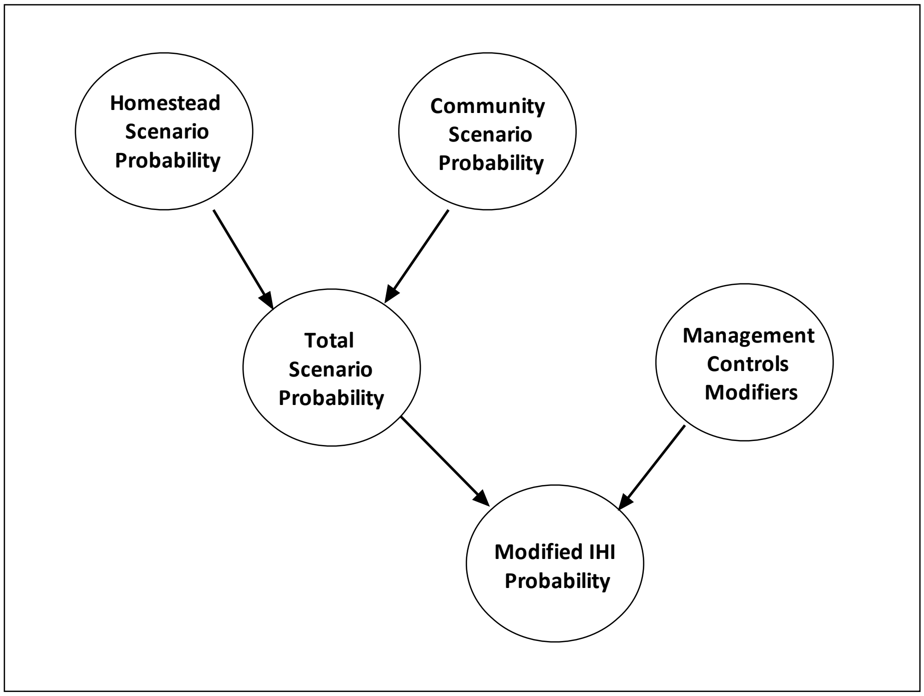


Figure 5.1 Top-Level Influence Diagram for IHI at an RWMS (after Black et al. 2001).

Influence diagrams were prepared for the homesteader and the three community scenarios. Figure 5.2 shows the influence diagram for the Jackass Flats Community Scenario, the largest contributor to the total scenario probability. The most sensitive input obtained from the SMEs, or the input contributing most to output uncertainty, was the fraction of time over the evaluation period (i.e., 10,000 years) that communities would be present in Frenchman Flat or Yucca Flat. The SMEs opinion was that communities would appear and disappear and be present in Frenchman Flat or Yucca Flats a total of 50% of the evaluation period or 5,000 years with an uncertainty range from 2,500 to 7,500 years.

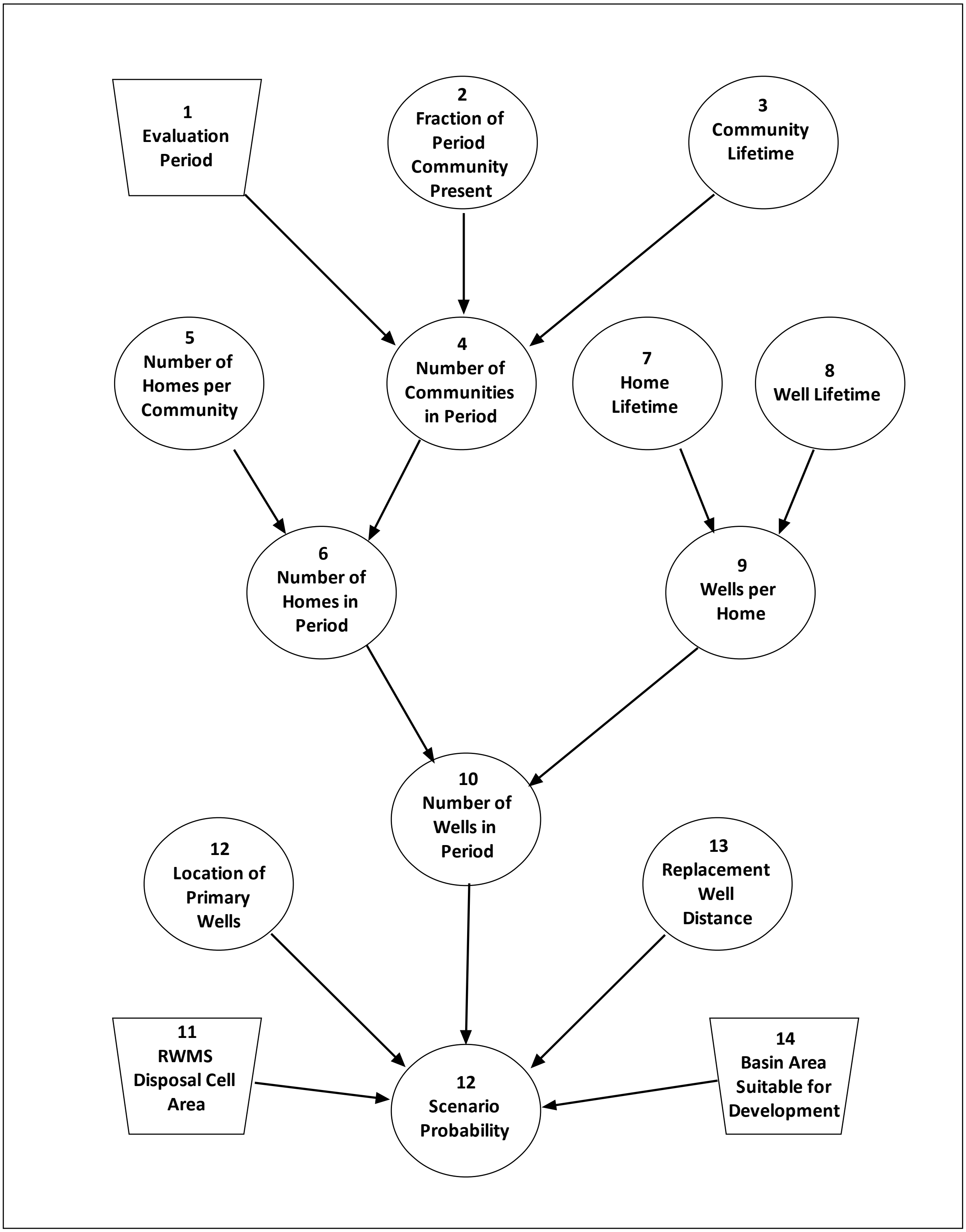


Figure 5.2 Jackass Flats Community Influence Diagram (after Black et al. 2001).

The next key simulation result is the number of wells drilled in the basin over the evaluation period (Table 5.1). The location of primary wells is randomly selected within the habitable area of the basin. Replacement water wells are randomly located within a stochastic distance of the primary well. The probability of intrusion by a primary well is similar to a binomial probability where the number of trials is the number of primary wells and the probability of success is the area of the RWMS disposal cells divided by the habitable area of the basin. The difference between the probabilities for Area 3 and Area 5 is due mostly to the SMEs opinion about the number of homes in Yucca Flat versus Frenchman Flat. The SMEs' opinion was that Yucca Flat communities would have half the homes of Frenchman Flat communities due to the greater depth to groundwater and the greater distance to supporting infrastructure.

Table 5.1 Mean Number of Wells and Probability of Intrusion for Homesteader and Community Scenarios Conditional on a 0.8-hectare Disposal Cell, 10,000-year Evaluation Period, and No Management Controls (Black et al. 2000)

RWMS	Scenario	Mean Number of Wells in 10,000 Years		Mean Probability of Intrusion in 10,000 Years†
		Primary	Replacement	
Area 3	Homesteader	24	3	0.0003
	Local Community	4	8	0.00002
	Las Vegas Expansion Community	29	200	0.00003
	Jackass Flats Community	2300	2800	0.007
Area 5	Homesteader	24	3	0.0003
	Local Community	4	8	0.0002
	Las Vegas Expansion Community	34	240	0.0003
	Jackass Flats Community	4600	5600	0.11

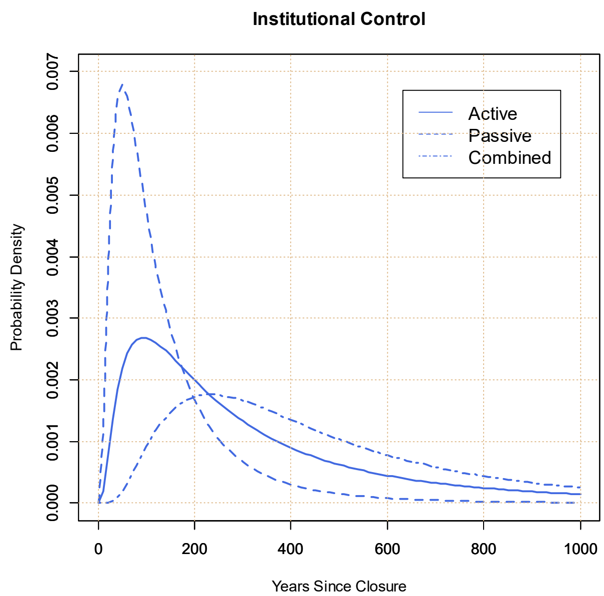
† - Assumes a 0.8-ha area for waste disposal cells

The probabilities in Table 5.1 are conditional on a 0.8-hectare (ha) disposal cell area, a 10,000-year evaluation period, and no management controls. The probabilities will increase with increasing disposal cell area, rising asymptotically to approach 1.0. The increase is not exactly linear due to the inclusion of replacement wells and the limitation that probability cannot exceed 1.0. The fiscal year (FY) 2019 estimate of the Area 3 and Area 5 RWMSs disposal cell areas at closure was approximately 10 and 30 ha, respectively. Without management controls, the expected (mean) probability of drilling intrusion in 1,000 years for the FY 2019 disposal cell areas would be approximately 0.7% at the Area 3 RWMS (U-3ah/at, U-3bh) and 32% for the Area 5 RWMS shallow land burial (SLB) disposal cells.

5.2 Management Controls

The SMEs were also elicited about the effectiveness of five management controls for preventing drilling intrusion. The SMEs considered administrative institutional controls, site knowledge, markers and placards, surface barriers, and subsurface barriers. The SMEs were queried regard how long administrative institutional controls and site knowledge would last and how markers and placards, surface barriers, and subsurface barriers would reduce the probability of intrusion. Subsurface and surface barriers are not currently in use at the Area 3 and Area 5 RWMSs and not considered further.

The SMEs opinions about the duration of administrative institutional controls and site knowledge were used to estimate distributions for the duration of active and passive institutional controls, respectively (Figure 5.3).



Years Since Closure	p(IC Period > Years Since Closure)		
	Active	Passive	Combined
10	1.00	1.00	1.00
100	0.82	0.50	0.97
250	0.49	0.14	0.74
500	0.23	0.03	0.38
750	0.13	0.01	0.20
1,000	0.08	0.00	0.11

IC – institutional control

Figure 5.3 Probability of the Duration of Institutional Controls at the Area 3 and Area 5 RWMSs Based on Elicitation of Subject Matter Experts

The SME's opinions about the effectiveness of signs and markers was used to estimate the probability that markers deter intrusion by millennia. Over the first 1,000-year interval, markers are assumed to have a 0.44 probability of deterring intrusion. The probability decreases each 1,000-year interval reaching a probability of 0.16 by 10,000 years.

5.3 FY 2019 Modified Probability of Intrusion

The FY 2019 probability of intrusion can be estimated by scaling the probability for the time of compliance and the area of the disposal cells. Scaling to 1,000 years and the FY 2019 disposal cell area gives a 0.7% and 32% probability of drilling intrusion at the Area 3 and Area 5 RWMSs, respectively (MSTS 2020a, NSTec 2011a) (Table 5.2).

Table 5.2 FY 2019 Estimate of the Mean Modified Probability of Intrusion in 1,000 Years

Mean FY 2019 Probability	Drilling		Construction	
	Area 3 RWMS Post-1988 Cells	Area 5 RWMS Post-1988 SLB Cells	Area 3 RWMS Post-1988 Cells	Area 5 RWMS Post-1988 SLB Cells
Mean Probability of Intrusion in 1,000 years: *P(IHI)*	0.007	0.3	0.005	0.2
Mean P(IHI) with ICs: $P(IHI)_{IC} = P(IHI) * (1 – f_{IC})$	0.004	0.2	0.002	0.1
Mean P(IHI) with ICs and Markers: $P(IHI)_{IC+M} = P(IHI) * (1 – f_{IC}) * (1 – M_{EF})$	0.002	0.08	0.001	0.06

f_{IC} – fraction of 1,000 years that ICs are effective (mean IC period = 537 years)
M_{EF} – probability markers are effective for 1,000 years (M_{EF} = 0.44)

The probability of construction intrusion is less than drilling because not every home has a pool, septic system, or basement while every home is assumed to have at least one well. The FY 2019 probability of construction intrusion estimate is 0.5% and 24% at the Area 3 and Area 5

RWMSs, respectively (MSTS 2020b, NSTec 2011b). The consequence of construction intrusion is expected to be greater than drilling.

The probability of intrusion must be modified for the duration of institutional controls and marker effectiveness. The mean period of institutional control is 537 years out of 1,000 years. The probability markers will be effective for 1,000 years was estimated to be 0.44 by the SMEs. The information provided by the SMEs suggests a 1,000-year mean modified probability of drilling intrusion of 0.002 and 0.08 for the Area 3 and Area 5 RWMSs, respectively (Table 5.2).

6.0 Implementation of IHI in Performance Assessment

A risk-informed approach to IHI considers the probability and consequences of intrusion in the selection of scenarios for optimization of waste concentration limits. Appropriate scenarios for optimization of waste disposal limits should have appreciable risk, where risk considers both the probability and consequence of IHI.

6.1 Area 3 RWMS

The probability of IHI at the Area 3 RWMS over 1,000 years is significantly less than the typically assumed value of 1.0. Evidence supporting a conclusion that the probability of IHI is low includes:

- No evidence of past human habitation within 15 km of the RWMS. The NNSS is in a region with some of the lowest population densities in the US.
- Absence of permanent surface water within 7 km of the RWMS.
- Absence of shallow groundwater. The uppermost aquifer below the RWMS is deeper than 99.9% of groundwater wells in Clark, Nye, and Lincoln Counties.
- No mineral resources occur in the thick alluvial deposits at the RWMS. No known mineral resources occur within 20 km of the RWMS.
- Low potential for petroleum resources.
- Yucca Flat is unsuitable for commercial irrigation agriculture. Past commercial efforts to graze cattle were unsuccessful.
- Numerous nuclear testing subsidence craters surround the RWMS, rendering the area unsuitable for development.
- Federal ownership of the site.
- Federal commitment to maintain institutional controls as long as necessary.
- Commitment to enforce FFACO UGTA URs on sub-surface activities.
- Enforcement of FFACO URs on the U-3ax/bl disposal cell and CAU 569 soil sites.

The most likely scenario for intrusion is the development of a community near Yucca Flat, perhaps in Jackass Flats or in the White Rock Spring area. This nearby community could support sparse rural development in Yucca Flat. SMEs evaluating IHI at the Area 3 RWMS provide information supporting a mean probability of intrusion of 0.2% or less in 1,000 years by drilling or construction with institutional controls and management controls. The 1,000-year probability of intrusion at the Area 3 RWMS is negligible. Combined with intruder doses that are a small fraction of the performance measure, the risk of intrusion at the Area 3 RWMS is very low.

Land use and resource availability in southern Nevada suggest a rural residential or industrial exposure scenario. Both scenarios have similar exposure pathways, but the residential scenario has longer exposure times than an industrial exposure. A rural residential exposure scenario would most likely not include agricultural pathways, but limited non-commercial agricultural exposure pathways are possible.

6.2 Area 5 RWMC

The probability of IHI at the Area 5 RWMS is very low, but perhaps slightly greater than at the Area 3 RWMS. Evidence supporting a conclusion that the probability of IHI is low includes:

- No evidence of past human habitation within 14 km of the RWMS. The NNSS is in a region with some of the lowest population densities in the US.
- Absence of permanent surface water within 14 km of the RWMS.
- Absence of shallow groundwater. The uppermost aquifer is deeper than 99% of groundwater wells in Clark, Nye, and Lincoln Counties.
- No mineral resources in thick alluvial deposits at the RWMS. No known mineral resources occur within 20 km of the RWMS.
- Low potential for petroleum resources.
- RWMS is unsuitable for commercial irrigation agriculture. Past commercial efforts to graze cattle were unsuccessful.
- Federal ownership of the site.
- Federal commitment to maintain institutional controls as long as necessary.
- Planned URs for the Area 5 RWMC.
- Enforcement of FFACO URs on CAU 111 and 577.

The most likely scenario for development is the appearance of a community near Frenchman Flat with rural development occurring in Frenchman Flat. Factors increasing the probability of intrusion relative to Area 3 include absence of nearby subsidence craters, closer proximity to developed infrastructure, shallower depth to groundwater, and a larger disposal cell footprint. SME's responses suggest an approximate probability of intrusion of 8% in 1,000 years with institutional controls and markers. Appropriate exposure scenarios are the same as for the Area 3 RWMS.

6.3 Recommendations for Application of IHI at the Area 3 and Area 5 RWMSs

Review of conditions at the NNSS indicates multiple factors reduce the potential for IHI including the lack of attractive resources near the RWMSs, the sparse settlement of the remote alluvium filled valleys of the region, and DOE commitments to use and maintain institutional controls. In addition, stakeholders have accepted institutional controls for management of legacy contamination and the low probability of intrusion based on SME elicitation. This paper recommends six assumptions concerning implementation of IHI analysis in the Area 3 and Area 5 RWMSs performance assessments and composite analyses.

1. DOE, NNSA/NFO, and its successors will implement, maintain, and enforce institutional controls consistent with their policies and directives, including FFACO policies and URs, at the Area 3 and Area 5 RWMSs as long as a hazard persists.
2. FFACO UGTA URs at the Area 3 RWMS will prohibit public access to contaminated groundwater within the NDEP negotiated compliance boundaries for 1,000 years. Similarly, NNSA/NFO institutional controls and FFACO URs on Area 5 RWMC will prohibit access for 1,000 years.
3. The low probability of intrusion combined with URs prohibiting access will eliminate the potential for long-term chronic intrusion. The Area 3 and Area 5 RWMS performance assessments will not evaluate chronic post-drilling and chronic construction (i.e., intruder-agriculture) intrusion scenarios. Institutional controls will not be 100% effective for shorter time spans (months) and will not prevent occurrence of acute drilling and construction scenarios.
4. The performance assessments will stochastically sample the duration of active and passive institutional controls from probability distributions based on the results of a site-specific SME elicitation. The lower limit of the institutional control period will be truncated at 100 years for DOE 435.1 performance assessments. The duration of institutional controls will remain fixed at 100 years for Title 40, Code of Federal Regulations Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," performance assessments.
5. FFACO URs are assumed to eliminate use of groundwater contaminated by underground testing for 1,000 years. This is assumed to eliminate the UGTA groundwater pathway from the composite analysis.
6. A quantitative probability of IHI will not be applied in risk-modified dose calculations consistent with the guidance of the National Academy of Sciences (NRC 1995)

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7.0 References

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