

2 **Evaluation of Subsurface Radionuclide Transport at**
3 **Commercial Nuclear Power Production Facilities**

4 ANSI/ANS-2.17 (Revised)

5 December 3, 2007

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34 **Foreword**

35 **Background**

36 This standard constitutes a major revision of the original standard, ANSI/ANS-2.17, which was adopted on
37 April 9, 1980, reaffirmed on October 3, 1989, and withdrawn on July 28, 2000. A new working group,
38 Working Group ANS-2.17R of ANS-2 Subcommittee (Site Evaluation) of the American Nuclear Standards
39 Committee, was constituted November 2005 to revise the original standard.

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57 **1. Purpose and Scope**

58 **1.1 Purpose**

59 This document provides guidance with respect to site characterization, performance confirmation
60 monitoring, and modeling efforts related to evaluating the occurrence and movement of radionuclides
61 within the subsurface at commercial nuclear power production facilities in accordance with appropriate
62 state and federal regulations. This standard is intended for use in facility design and permitting, operation,
63 and closure. This document contains mandatory requirements as designated by the word “shall”.

64 **1.2 Coverage**

65 This document addresses radionuclide releases that affect: i) groundwater, ii) surface waters affected by
66 groundwater, and iii) water supplies derived from groundwater. This document addresses subsurface
67 radionuclide transport resulting from normal and abnormal radionuclide releases.

68 **1.3 Exclusions**

69 This document does not address the subsurface occurrence and movement of non-radioactive materials,
70 other than as indicators of subsurface radionuclide occurrence and movement in soil and groundwater. This
71 document does not address the surface occurrence and movement of radionuclides, except to the extent that
72 surface radionuclide occurrence and movement may affect onsite subsurface radionuclide occurrence and
73 movement. This document does not address corrective action, which may be required as a result of a
74 radioactive release to groundwater.

75 **1.4 Consultation**

76 It is strongly recommended that all regulatory agencies be consulted prior to the preparation of the scope of
77 work for evaluation of subsurface radionuclide transport. It is also advised that relevant data, information,
78 and technical studies be used from all available sources. Substantial pre-construction and post-construction
79 data and information may be available at existing facilities, although these may not be in suitable digital
80 format. Additional data can be solicited from federal sources, such as the U.S. Geological Survey, the U.S.
81 Army Corps of Engineers, the U.S. Bureau of Reclamation, the Natural Resources Conservation Service,
82 the U.S. Forest Service, the Tennessee Valley Authority, the U.S. Environmental Protection Agency, the
83 Nuclear Regulatory Commission, the Agricultural Research Service, the U.S. Fish and Wildlife Service, the
84 Bureau of Land Management, and the U.S. Department of Energy. Additional interstate, state, tribal,
85 regional, and local agencies and authorities, as well as non-governmental organizations, and others with
86 technical information in the area of interest should also be consulted.

Comment [A1]: It is stated that all regulatory agencies be consulted prior to preparation of the scope of work. In my opinion, it might be more beneficial if there is a standing committee or an interagency working group that works in close collaboration on a scheduled time frame rather than having a one time effort as needed.

Comment [A2]: This is not clear. What are the goals, purposes, expectations, content, and procedures of the consultation?

Comment [A3]: We suggest deleting all mention of specific agencies in lines 80-84, or else listing only lead agencies, in particular NRC and EPA.

Comment [A4]: Listing of agencies, authorities and organizations to be consulted would benefit from collaborating with the Advisory Committee on Water Information and more specifically the Subcommittee on Groundwater.

87 **2. Definitions**

88 *ALARA, As Low As Reasonably Achievable:* To make every reasonable effort to maintain exposures to
89 ionizing radiation as far below the dose limits as practical, consistent with the purpose for which
90 the licensed activity is undertaken and taking into account the state of technology, the cost of
91 improvements in relation to state of technology and benefits to the public health and safety, and
92 other societal and socioeconomic considerations.

93 *Ambient borehole flow:* Natural vertical flow (up or down) within an open borehole or well due to the
94 surrounding vertical hydraulic gradients.

95 *Ambient groundwater flow:* Natural horizontal and vertical subsurface flow.

96 *Aquifer:* A geologic formation, group of formations, or part of a formation that contains sufficient saturated
97 permeable material to yield significant quantities of water to springs and wells.

98 *Aquifer, confined:* An aquifer bounded above by a low-permeability layer.

99 *Aquifer, unconfined:* An aquifer whose upper surface is a water table.

100 *Background concentration, natural:* A concentration of a substance in a particular environment that is
101 indicative of minimal influence by human (anthropogenic) sources.

102 *Background concentration, local:* The concentration or activity of a substance that is indicative of local site
103 conditions prior to the operation of the nuclear facility.

104 *Background concentration, regional:* The concentration or activity of a substance that is indicative of
105 regional conditions prior to the operation of the nuclear facility.

106 *Capillary zone:* The region above the water table where pores are saturated, but the water gage pressure is
107 negative; also called the *tension saturated zone*.

108 *Site conceptual model:* An abstract, qualitative representation of the relevant flow and transport features,
109 events, and processes that affect subsurface radionuclide transport at the site.

110 *Confining layer:* A geologic unit of distinctly lower hydraulic conductivity than the underlying and
111 overlying geologic units.

112 *Contamination:* Undesired radioactive material that is deposited on the surface of or inside structures,
113 areas, objects, or people.

114 *Corrective action:* Activities undertaken to manage or remediate the occurrence or movement of subsurface
115 radionuclides.

116 *Data quality objectives:* A strategic planning approach based on the Scientific Method to prepare for a data
117 collection activity. It provides a systematic procedure for defining the criteria that a data collection
118 design should satisfy, including when to collect samples, where to collect samples, the tolerable

Comment [A5]: Define this term. Also, this is presumably the same as “fluid gage pressure” (line 158) and “gage fluid pressure” (line 179) – decide on a single term.

Comment [A6]: Define – or better yet, rewrite to eliminate reference to this broad and ambiguous term.

119 level of decision error for the study, and how many samples to collect, balancing information
120 needs with costs in an acceptable manner.

121 *Dual porosity model*: A transport model applied to a porous medium composed of two porosity fractions or
122 domains. One porosity fraction stores and transmits solute (mobile porosity or domain), while the
123 other porosity fraction only stores solute (immobile porosity or domain). Solute exchange between
124 the mobile and immobile porosities occurs.

125 *Engineered barrier*: A man-made cover, wall, or device used to prevent contaminants from entering or
126 moving through the subsurface, or to retard horizontal subsurface flow.

127 *Exfiltration*: The movement of water across the ground surface from the subsurface as seepage.

128 *Features, events, and processes*: A statement of the relevant: i) Features related to site conditions and
129 radionuclide inventories along with the effects of radionuclide releases; ii) Events related to
130 incidents that may result in normal and abnormal radionuclide releases; and iii) Processes related
131 to site liquid and vapor transport pathways, as well as the physical and chemical processes that
132 govern transport along the pathway.

133 *Fluid velocity, average pore*: The fluid velocity within pores averaged over a representative elementary
134 volume of pores.

135 *Fluid velocity, classical*: The time rate of displacement of a fluid particle.

136 *Groundwater*: All water contained in pores at or below the **watertable**. This term also identifies water in
137 the phreatic zone.

138 *Groundwater flux*: The volumetric discharge per unit cross-sectional area of medium (solids plus pores);
139 also called the *Darcy flux*.

140 *Groundwater, perched*: Unconfined subsurface water collecting on low permeability sediments that are
141 separated from an underlying main body of groundwater by an unsaturated zone.

142 *Groundwater recharge*: The process involved in the addition of water to the phreatic zone; also, the amount
143 of water added.

144 *Infiltration*: The movement of water across the ground surface into the subsurface.

145 *Monitored Natural Attenuation, MNA*: The monitoring of the attenuation of radionuclides, over time and
146 space, due to natural processes (decay, dilution, sorption, hydrodynamic dispersion etc), in a
147 manner that reasonably insures human health and the protection of the environment.

148 *Percolation*: The movement of water through a porous medium, such as soil or rock.

149 *Performance assessment*: A systematic analysis of the potential exposures posed by waste management
150 systems to the public and environment, and a comparison of those exposures to established
151 performance objectives.

Comment [A7]: Two words ("water table") is standard – see line 158.

152 *Performance-based regulation*: Regulations that are outcome-oriented rather than procedure-oriented.

153 *Performance objective*: A statement defining compliance with a system design or regulatory requirement.

154 *Performance indicator*: An **observable metric** used to determine whether or not a performance objective
155 has been achieved.

156 *Performance threshold*: a quantitative criterion for each performance indicator that assures that
157 performance objectives can be, or are being, met

158 *Phreatic zone*: The region below the water table where fluid gage pressure is greater than or equal to zero.

159 *Porosity*: The ratio of the volume of pores (or voids) in soil or rock to the total solid plus pore volume.

160 *Radionuclide release, abnormal*: The non-approved spill, leak, or accidental release of radionuclides to the
161 environment that is not intended and uncontrolled.

162 *Radionuclide release, normal*: The pre-approved, monitored release of radionuclides to the environment,
163 including permitted releases as well as non-permitted, controlled releases of low-level radioactive
164 materials. Normal radionuclide releases should be as low as reasonably achievable (ALARA).

165 *Risk-significant*: When used to qualify an object, such as a system, structure, component, accident
166 sequence, or **cut set**, this term identifies that object as exceeding a predetermined criterion related
167 to its contribution to the risk from the facility being addressed. One that is associated with a level
168 of risk that exceeds a predetermined significance criterion. *Saturated zone*: The zone in the
169 subsurface where the pores are filled with water (phreatic zone plus capillary zone).

170 *Subsurface*: All rock, soil, and fill material below the ground surface.

171 *Subsurface water*: Water contained within pores below the ground surface.

172 *System performance*: A quantitative measure of the ability of an engineered or natural system to meet
173 performance objectives.

174 *Tritium*: A radioactive isotope of hydrogen, primarily found as part of tritiated water, HTO.

175 *Unsaturated zone*: **The zone between the ground surface and the top of the capillary zone in which pores**
176 **are not completely filled with water.**

177 *Vadose zone*: The region between the ground surface and the water table where the water gage pressure is
178 negative.

179 *Water table*: The water surface in an unconfined aquifer corresponding to zero gage fluid pressure.

Comment [A8]: This term is ambiguous. Do you mean a quantitative standard, or an observable quantity that is intended to be compared against such a standard? A little Google-ing shows examples of both senses.

Comment [A9]: Define or eliminate. This is a really obscure term for a non-specialist.

Comment [A10]: Suggested replacement: "A subsurface region where pores are filled partially with water and partially with air, most commonly the zone between the ground surface and the top of the capillary zone.". (An unsaturated zone can occur below perched groundwater.)

180 3. Performance Assessment Methodology

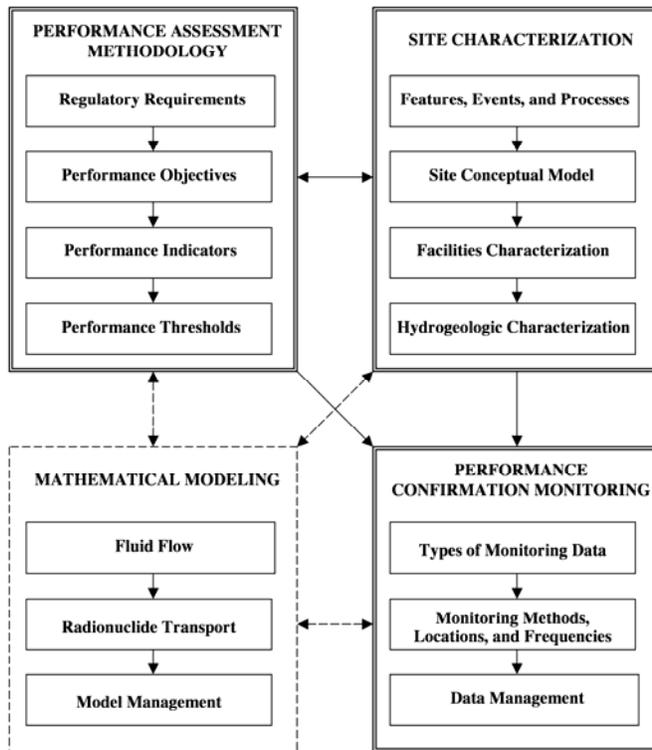
181 This standard uses the performance-assessment methodology, which is an **outcome-oriented process** for
182 providing credible, objective data and information about potential radiological exposures to the public and
183 environment and for demonstrating whether or not these exposures comply with system design or
184 regulatory requirements. Performance assessment uses site characterization and performance confirmation
185 monitoring, along with conceptual and mathematical models, to understand the different geologic,
186 hydrologic, physical, and chemical processes that affect system performance. This understanding is used to
187 develop and evaluate alternative site designs, monitoring strategies, and closure procedures, with the
188 objective of demonstrating the ability to meet system design or regulatory requirements.

Comment [A11]: Define.

189 System performance is used to assure that an engineered or natural system is able to meet system design or
190 performance objectives. . In the context of this standard, the system is comprised of: (1) all facilities from
191 which a release to the groundwater could occur, (2) all facility policies or procedures which may impact or
192 cause a release, (3) the man-machine interface of a facility which may cause or contribute to a release, (4)
193 all engineered barriers and leak detection systems, (5) a working or conceptual understanding of the local
194 and regional geology and hydrogeology, and (6) all monitoring well networks and procedures for gathering
195 and analyzing groundwater samples. Thus, system performance is a key feature of demonstrating
196 compliance with regulatory requirements. In the context of evaluating subsurface radionuclide transport, a
197 quantitative evaluation of system performance requires an understanding of the hydrogeologic and
198 geochemical system. This understanding is based on characterization of the hydrogeologic system
199 (including geochemistry), monitoring of system behavior, and simulation of flow and transport.

200 Specifically, a performance assessment establishes:

- 201 • The *regulatory requirements* for the facility or activity, including federal, state, tribal, and local rules
202 and regulations;
- 203 • The *performance objectives*, which are defined outcomes that demonstrate compliance with system
204 design or regulatory requirements;
- 205 • The *performance indicators*, which are observable metrics that are used to determine whether the
206 performance objectives can be, or are being, met; and
- 207 • The *performance thresholds*, which are quantitative criteria for each performance indicator that assure
208 that performance objectives can be, or are being, met.



209

210 **Figure 1.** Flow chart describing relationships between performance assessment methodology, site
 211 characterization, performance confirmation monitoring, and mathematical modeling. Solid lines indicate
 212 mandatory activities, while dashed lines indicate where additional modeling efforts can be used when
 213 complex site conditions are present.

214 3.1 Regulatory Requirements

215 Regulatory requirements include those associated with facility design and permitting, operation, and
 216 closure. A range of regulatory requirements may exist for a specific site, including maximum or cumulative
 217 exposures, maximum concentration, etc., at a variety of different compliance points, including drinking
 218 water wells, boundary limits, the water table, etc., and over specific time periods. All relevant regulatory
 219 entities shall be consulted and specific regulatory programs and objectives related to groundwater
 220 protection shall be determined. It is advisable to discuss the specific site with all appropriate regulatory
 221 agencies prior to the preparation of the scope of work for evaluation of subsurface radionuclide transport.
 222 Regulatory agencies include the U.S. Nuclear Regulatory Commission, the U.S. Environmental Protection
 223 Agency, as well as interstate, state, tribal, regional, and local regulatory agencies and authorities.

Comment [A12]: This figure should be referenced in the text. Also, it looks like boxes represent activities, and lines represent information flow or feedbacks.

Comment [A13]: Lines or boxes?

Comment [A14]: Since there is a two way link between the process blocks which is indicative of a repeating information flow, will it be possible to formulate an objective function from the performance objectives and optimize the process?

Comment [A15]: Much of this section is essentially duplicated in 3.4, below.

224 3.2 Performance Objectives

225 A range of performance objectives should be used to demonstrate compliance with system design and
226 regulatory requirements. Performance objectives correspond to critical outcomes that rely on site
227 characterization, performance confirmation monitoring, and modeling efforts to demonstrate that system
228 design and regulatory requirements are met. A likely performance objective is the absence of radionuclides
229 in groundwater at concentrations that exceed a performance threshold. Demonstrating that a performance
230 objective is met requires the selection of performance indicators, such as tritium concentrations in
231 monitoring wells, and the specification of performance thresholds for those indicators, such as a
232 radiological activity that statistically exceeds a specified level.

Comment [A16]: Definition needed.

Comment [A17]: The performance objective is described as a set of critical outcomes that rely on a set of factors. In the event a performance objective is not met, it might be necessary to consider regulatory action as mandated by law. In addition to the regulatory action, will the performance objectives prescribe outcome based mitigation guidelines in support of the overall goal?

233 3.3 Performance Indicators

234 Selection of performance indicators requires an observable metric that can be used to evaluate
235 unambiguously whether a performance objective is being met. Tritium concentration is likely to be selected
236 as a performance indicator because of its prevalence within nuclear facilities, and its high mobility. Other
237 radionuclides can also serve as indicators and should be used if they are likely to be present and are mobile
238 in the environment. Water quality parameters that may indicate a radionuclide release include specific
239 conductance, pH, boron concentration, nitrate concentration, and turbidity. Physical measurements that
240 may indicate a radionuclide release include water-level changes in the surficial aquifer, low spots or sumps,
241 as well as groundwater temperature anomalies, increased seepage rates and increased soil moisture content.

Comment [A18]: See note at line 154.

242 3.4 Performance Thresholds

243 Deciding whether performance objectives have been met requires the specification of a performance
244 threshold for each performance indicator. For example, deciding whether a radionuclide release has
245 occurred might be based on a specific tritium concentration as a performance threshold. An observed
246 concentration that statistically exceeds this threshold would trigger a sequence of responses depending
247 upon the magnitude and extent of the release.

248 Performance thresholds should be based on the performance objectives and should be developed using
249 knowledge of flow and transport at the site as incorporated in the site conceptual model, as well as the
250 geochemical properties of the indicator. Exceeding the performance threshold should trigger either
251 operational or procedural changes, design changes, increased monitoring (frequency and spatial density), or
252 other corrective actions. Criteria that determine the performance threshold could be based on statistically
253 significant deviations from local background concentrations or an alternative radiological threshold as
254 defined by performance objectives. These criteria can be based on radionuclide concentrations (either
255 volume-averaged or flux-averaged), travel times, mass fluxes, or predicted doses.

256 Evaluating whether performance thresholds have been exceeded can be based on performance indicators
257 using monitoring data supplemented with modeling results. If monitoring data demonstrate that a
258 performance indicator has exceeded its performance threshold, then a predetermined response should be
259 invoked. Steps in a response include resampling and analysis, additional assessment (well integrity,
260 analytic integrity), and installation of additional monitoring facilities (e.g., additional wells or geoprobes).
261 If these steps are taken, and the performance threshold continues to show exceedance, then corrective
262 action may be undertaken.

Comment [A19]: The trade name "Geoprobe" should be capitalized, or better replaced with "direct push samples".

263 **4. Site Characterization**

264 The purpose of site characterization is to support performance assessment by providing data and
265 information about the regional and local hydrogeologic system, as well as information about site facilities,
266 as they may affect subsurface flow and transport. The degree of effort associated with the characterization
267 effort will depend upon the complexity of geologic and hydrologic conditions, the types of radioactive
268 materials and facility components present at the site, the types and effectiveness of engineered barriers, and
269 the proximity to surface water and groundwater receptors. Thus, a multi-tiered strategy is prescribed herein
270 that sets forth a minimum set of characterization activities at all sites, with additional efforts required at
271 sites with greater complexity and receptor proximity.

272 **4.1 Features, Events and Processes**

273 Site characterization is intended to assist performance assessment by providing quantitative data and
274 information quantifying the Features, Events, and Processes (FEPs) that control subsurface occurrence and
275 movement of radionuclides. Defining the *features* requires an understanding of the overall system as
276 defined previously, including site conditions and inventories along with the effects of radionuclide releases.
277 Defining the *events* requires the ability to identify and define normal and abnormal radionuclide releases.
278 Defining the *processes* requires the ability to specify the physical and chemical phenomena that determine
279 the movement of water and radionuclides within the subsurface, as well as the pathways between the source
280 and potential receptors.

281 The characterization effort shall identify features, events, and processes by:

- 282 • Identifying the *facilities* that contribute to, or affect the release of, radionuclides, including
283 radionuclide sources, pathways, travel times, concentrations, and radiological exposure;
- 284 • Using regional and local hydrogeologic studies to define the *conceptual model*, which provides the
285 framework for identifying and designing site characterization activities related to subsurface flow and
286 radionuclide transport; and
- 287 • Providing quantitative data and information about *processes and parameters* that allows for the
288 development of a mathematical (parametric) model that can be used to help understand and manage the
289 geologic, hydrologic, and geochemical environment at the facility.

290 **4.2 Site Conceptual Model**

291 The site conceptual model provides the framework for identifying and designing site characterization
292 activities (USNRC, 2003). As such it contains the fundamental assumptions used for understanding and

Comment [A20]: Reverse the first two bullet points to match the order of sections 4.2 and 4.3.

Comment [A21]: Before contamination, it is possible to identify potential facilities and sources of contaminations at a site, but it is impractical to identify all potential pathways, travel times and concentrations because simply there are too many. Therefore, during the planning stage, we consider the most severe accident only. After identifying a contamination, further detailed characterization will be possible. The standard needs to make clear that more than one stage of characterization may be necessary.

Comment [A22]: Sections 4.2 through 4.5 are specified in the Standard Review Plan (see reference in general comments). Discussions of groundwater and accidental releases are included in Sections 2.4.12 and 2.4.13 in the Final Safety Analysis Report (FSAR) for each site. The FSAR also includes most other site-specific information. Again, after a contamination happens, further detailed site characterization should be done for prediction and remediation of the contamination.

293 describing the physical, hydrologic, and geochemical processes that affect the near- and long-term
294 consequences associated with subsurface radionuclide releases.

295 The conceptual model shall **define** the geographic region of concern. It is likely that the region will include
296 surface water basins (upstream and downstream), as well as those coastal areas or regional aquifers that are
297 likely to be directly affected by radionuclide releases. Adjacent watersheds shall also be included in the
298 conceptual model for those cases where subsurface flow between watersheds is likely to be present.

Comment [A23]: This word should be "cover", or possibly "describe". The area was likely "defined" (in the sense of being selected) by some prior activity, such as selection of the site.

299 The conceptual model shall define the significant regional hydrologic features, including relevant rivers
300 and streams, lakes and ponds, wetlands, and estuaries. The local surface hydrologic features shall be
301 identified, including perennial and ephemeral rivers and streams, lakes and ponds, wetlands, and estuaries.

302 The conceptual model shall define the significant geologic features, including the general stratigraphy and
303 lithology, along with regional faults, fracture systems, conduits, and large voids, if present. The significant
304 hydrogeologic units, including the aquifers and confining units (aquitards) shall be summarized and
305 mapped. In addition, interactions between aquifers (leakage) and between surface- and ground-water
306 systems (recharge and discharge) shall be described. Geochemical processes that may affect radionuclide
307 occurrence and transport shall be described.

308 The conceptual model shall also be consistent with regulatory requirements, performance objectives, and
309 performance indicators. This will require that the receptor locations, regulatory boundaries, and target
310 aquifers be identified. While the water-table aquifer is likely to be the target aquifer to be protected,
311 hydrogeologic conditions may warrant the identification of other hydrogeologic units, such as underlying
312 confined and semi-confined aquifers, as well as the overlying vadose zone. The performance objectives
313 shall be specified based on system design and regulatory requirements, with the goal being the ability to
314 demonstrate that system design and regulatory requirements are met. Selection of performance indicators
315 shall reflect the likely inventory of radionuclides, in conjunction with the likely scenarios that could result
316 in an abnormal release. At a minimum, tritium shall be the performance indicator, with additional
317 indicators selected based upon site-specific conditions.

318 Alternative conceptual models shall be proposed at complex sites (e.g., where fractures or heterogeneities
319 may substantially affect transport behavior) as alternative hypotheses that are suitable for testing using
320 additional characterization or monitoring data. Alternative interpretations regarding the major lateral,
321 upper, and lower hydrologic boundaries of the unconfined aquifer and any other physical boundaries (e.g.,
322 surface-water bodies, surface outcrops, recharge boundaries) shall be provided if appropriate.

323 **4.3 Facilities Characterization**

324 This section focuses on those specific components, procedures, and processes of a nuclear facility for
325 which a failure may occur, with the goal being to identify the failure modes along with the probabilities of

326 failure of those components. This information will be used for specifying subsequent characterization,
327 monitoring, and modeling efforts.

328 Radionuclide inventories shall be provided for each facility component from which a release to the
329 subsurface could occur (spent fuel pools, holding ponds, condensate tanks, etc.). Locations of potential
330 radionuclide releases shall be identified. The discharges, concentrations, activities, and loads of all
331 radionuclide releases shall be provided. The locations of existing and likely future subsurface radionuclide
332 plumes resulting from radionuclide releases shall be mapped. Regional groundwater and surface water uses
333 and potential receptors shall be provided. Travel paths and travel times to potential receptors shall be
334 provided.

Comment [A24]: This must be historical data.

335 Surface facilities (holding ponds, tanks, pipelines) shall be inventoried and their characteristics shall be
336 provided. Subsurface facilities (including drains, pipes, conduits, backfill, pads, foundations, and the
337 associated vadose zone) shall be inventoried and their characteristics (location, depth, size, etc.) shall be
338 provided. Engineered barriers (cutoff walls, tell-tales, and interceptor wells) shall be inventoried and their
339 characteristics (location, capacity, and monitoring frequency) shall be provided. All fill materials shall be
340 inventoried and their characteristics (location, volume, hydraulic properties) shall be provided.

341 Well completion data shall be provided, including details of well construction, such as grouted and screen
342 intervals, screens, casing type, depth, diameter, perforation, and surface seals, aquifers penetrated, location,
343 elevation, use, owner, discharge rates, static hydraulic heads, and drawdown. Abandoned wells and
344 piezometers used for site investigations should be identified and described and the method of abandonment
345 shall be provided.

346 The hydrogeologic regime may be altered due to construction and ongoing facility modifications. Surface
347 and subsurface modifications shall be catalogued and updated to reflect actual site conditions. Changes in
348 groundwater conditions resulting from new and previous facility construction and operation, shall be
349 provided. These changes may be due to groundwater control or foundation improvement activities such as
350 installation of slurry trenches and rock grouting, and may include changes in hydraulic heads within
351 pertinent aquifers, changes in hydraulic conductivity, and changes in the direction or quantity of
352 groundwater flow. In addition, anticipated changes in water quality due to, for example, intrusion of saline
353 water, stormwater or irrigation water infiltration, domestic and municipal wastewater disposal, and induced
354 movement within or between aquifers shall be provided.

355 All facility policies and procedures that may affect the potential release and subsequent movement of
356 radionuclides to the environment shall be identified.

Comment [A25]: "Hydrogeologic Characterization of Processes and Parameters"

357 **4.4 Hydrogeologic Characterization**

358 A wide range of site hydrogeologic characterization activities is required to accurately describe the
359 important processes and parameters at a site. These activities will assist in performance assessment, by

360 guiding the specification of performance objectives, indicators, and thresholds. The data and information
361 will also assist in determining the appropriate monitoring frequency and locations, and for providing
362 parameters required for mathematical modeling. Data from regional studies shall be used to plan the
363 detailed site studies. Some characterization activities may duplicate other ANS studies, and can be utilized.
364 Additional technical documents related to groundwater characterization are available, including USNRC
365 (1988) and NEI (2007).

366 **Baseline Conditions.** Ambient subsurface flow conditions are needed to establish a baseline against which
367 future conditions can be compared. Characterization of hydraulic head, hydraulic head gradients (flow
368 magnitude and direction), and the natural variation and bounds of these estimates shall be provided for the
369 unconfined aquifer, and for the uppermost confined aquifer, if present. A general description of hydraulic
370 conditions in the vadose zone and possible limiting behavior (e.g., potential flooding or full saturation)
371 shall be provided as well.

372 Hydraulic heads in nearby surface waters (e.g., rivers, lakes, wetlands, springs, estuaries, bays, oceans)
373 shall also be provided and compared with subsurface observations. The relationships between observed
374 surface water and subsurface hydraulic heads shall be used to estimate the average and range of hydraulic
375 head response, as well as their effects on the magnitude and direction of subsurface transport at the facility.
376 For sites where aquifer hydraulic heads are affected by changes in surface loading (e.g., precipitation,
377 barometric pressure, streamflow, tidal fluctuations, cooling water intake and discharge canals), then the
378 response to these processes shall also be quantified. ||

379 A water budget for the site shall be prepared showing the precipitation, evapotranspiration, runoff, recharge
380 and discharge. The recharge-discharge relationships between surface water and groundwater (and between
381 aquifers, if appropriate) shall be estimated. Local and regional groundwater recharge and discharge areas
382 shall be identified and mapped. The temporal variation in these areas shall be estimated for both short- and
383 long-term interactions. Interactions include artificial recharge from past and current site operations, as well
384 as natural recharge from direct infiltration of precipitation, surface water, and site runoff. Long-term
385 changes in regional recharge and discharge that affect radionuclide transport shall be projected for several
386 periods over the facility lifetime (e.g., at 10-year intervals) and for various conditions of aquifer recharge
387 and discharge.

388 **Physical Properties.** The physical properties of hydrogeologic units appropriate for understanding and
389 predicting radionuclide transport at the site shall be provided. Of primary interest are the physical
390 properties that affect flow and transport characteristics, including the total and effective porosity, pore and
391 grain size distributions, and solids surface area. Special interest shall be placed on the physical properties of
392 features that may compromise system performance, such as fractures and large conduits, including their
393 frequency, dimensions, orientation, and interconnectivity. Spatially explicit data shall be collected, using
394 continuous soil or rock samples as well as surface and subsurface (borehole) geophysical methods.

Comment [A26]: Insert following after: "Conditions shall be monitored long enough and frequently enough to define the probable range of variations."

Comment [A27]: The baseline data and characterization need to address the unique hydrogeologic setting of coastal aquifers by gathering data and prior modeling results for submarine discharges and tidal influence on the hydraulic head in the aquifer as well as the variable density of flow in the presence of saltwater intrusion.

395 **Hydraulic Properties.** Characterization shall be performed for those hydrogeologic units that significantly
396 affect radionuclide transport. One or more test borings shall be performed, some of which should be used to
397 collect continuous core through the unconfined aquifer, and the underlying confining bed and confined
398 aquifer, if present. Borehole geophysical logs should be collected from selected test borings. In-hole flow
399 tests should be conducted in selected test borings to identify zones with higher flow rates.

Comment [A28]: In-hole horizontal and vertical ...

Comment [A29]: ... borings, if appropriate, to identify ...

Comment [A30]: It isn't clear here whether tests under natural flow conditions or under pumping conditions, or both, are being recommended.

400 Quantitative estimates of relevant hydraulic parameters (e.g., hydraulic conductivity, transmissivity,
401 specific storage, storativity, leakance) shall be provided using aquifer tests (e.g., single and multiple
402 borehole pumping tests, slug tests, specific capacity tests, falling/rising head tests, borehole flowmeter
403 tests), surface and borehole geophysical and geotechnical investigations along with associated monitoring.
404 For anisotropic media, the directional components of hydraulic properties shall be provided. Special
405 interest shall be placed on the hydraulic properties of features that may compromise system performance,
406 such as fractures and large conduits. Vadose zone characteristics shall be provided, including moisture
407 characteristic curves and the unsaturated hydraulic conductivity functions, if they substantially affect
408 radionuclide transport. A practical way to accomplish this is to use the Van Genuchten functions based on
409 particle size distributions (Schapp et al., 2001).

410 Estimates of ambient flow magnitudes and directions shall be provided for a range of hydrologic
411 conditions. These estimates should be confirmed using tracer or borehole (e.g., in situ borehole flow-meter)
412 methods.

413 **Geochemical Properties.** Sufficient data shall be provided to define the fluid chemistry and potential
414 reactions of formation fluids and solids with released fluids. Appropriate transport characterization
415 parameters (e.g., total ion-exchange capacity, distribution coefficients, pH, redox) shall be provided for
416 performance indicators that are affected by geochemical processes.

417 **Transport Properties.** Sufficient data shall be provided to define the normal and abnormal background
418 concentrations of the performance indicators, likely to be tritium and/or another radionuclide, at and near
419 the facility. Natural background concentrations in both soil and groundwater shall be determined, as well as
420 regional background concentrations that account for anthropogenic activities. Regional trends shall be
421 evaluated with respect to these sources.

422 The spatial and temporal variability of concentrations of performance indicators in precipitation, surface
423 water, and groundwater shall be provided in a format that allows for the specification of performance
424 thresholds.

425 Water quality data should also be collected for resolving ambiguities in the conceptual model, such as to
426 identify modes of recharge to the aquifers, flow within complex hydrogeologic environments, and to assess
427 the interaction of groundwater between geologic formations. Tracer tests can also be performed to resolve
428 ambiguities in the conceptual model

429 **5. Performance Confirmation Monitoring**

430 The purpose of monitoring is to support performance assessments by providing assurance that the facility
431 complies with performance objectives and meets necessary state and federal regulatory standards. This
432 over-arching purpose can be broken down into specific monitoring objectives, including:

- 433 • Determining the source, magnitude, migration rate, and potential exposures associated with a detected
434 release; and
- 435 • Providing data useful for conceptual and mathematical modeling, supporting hydrologic parameter
436 estimation, and determining whether a radionuclide release has occurred.

Comment [A31]: Insert bullet:
“Determining the seasonality of
monitored results and the
interdependence on release patterns and
local hydrometeorology.”

437 Both monitoring efforts are critical – the first is reactive in the sense that data are critical for guiding
438 interdiction when a release has been detected, and the second is proactive in the sense of that data are
439 critical to designing, installing, and maintaining an active monitoring program.

440 **5.1 Types of Monitoring Data**

441 Tritium will likely be the key performance indicator that will be used to demonstrate compliance with
442 performance objectives. In addition to tritium, monitoring for other radionuclides will depend upon the
443 anticipated inventory or release scenarios at the site, along with other factors including the solubility,
444 mobility, and volatility of the radionuclide. Screening measurements (e.g., gross alpha, gross beta, total
445 gamma activity) should be used as an indicator of radionuclide presence. Additional water analytes (e.g.,
446 temperature, specific conductance, pH, turbidity, dissolved oxygen, redox, boron) should be used as
447 indicators of radionuclide release based on knowledge of the source term.

Comment [A32]: These three terms
need to be defined in Section 2.

448 Physical changes in the local hydrology should be used to provide an early indication of radionuclide
449 releases. Changes in the hydraulic head or flow in the absence of corresponding natural hydrologic events
450 could serve as warnings for a radionuclide release.

Comment [A33]: Insert paragraph
after: “Sampling methods and equipment
shall be standardized and documented as
early as possible in the monitoring
program in order to avoid spurious
variation in monitored parameters
resulting from inconsistent sampling
techniques. The importance of this point
cannot be over-emphasized.”

451 **5.2 Monitoring Methods, Locations, and Frequencies**

452 While water samples have traditionally been collected from permanent, long screen monitoring wells or
453 piezometers, vertical ambient flow in such wells may compromise water samples (Elci et al., 2001, 2003).
454 In place of long-screen wells, various types of multilevel sampling wells are available, along with methods
455 for converting long-screen wells into multi-level samplers. Water samples from these intervals shall be
456 collected using a variety of sampling devices (portable pumps, dedicated pumps, bailers, etc.) and sampling
457 techniques (purging multiple well volumes, low flow sampling, no purge sampling) from wells installed to
458 meet regulatory compliance and performance standards.

Comment [A34]: This section should
address the sampling frequency in time,
including relevant scientific bases and
regulatory standards for radionuclides.
Also needed is a discussion of sampling
accuracy and errors.

Comment [A35]: Insert after:
“Samples shall be taken over short
vertical intervals whenever possible.”

Comment [A36]: ... the most
appropriate from among the available ...

459 Gas-phase sampling should be used to determine the presence of volatile radionuclides, such as tritium,
460 carbon-14, helium-3, and iodine-129. Samples are normally taken to laboratories for analysis.

461 Water quality monitoring should be performed *in situ*, where appropriate, using dedicated water-quality
462 probes (e.g., temperature, specific conductance, pH, turbidity, dissolved oxygen, redox, gross alpha, gross
463 beta, gamma). *In situ* probes allow for the early detection of hydrologic changes resulting from
464 radionuclide releases.

465 The hydraulic head shall be monitored using pressure transducers or capacitance probes placed in nested
466 piezometers installed at multiple depths in the saturated zone, and by using tensiometer probes in the
467 unsaturated zone. The hydraulic head in the unsaturated zone should be inferred, where appropriate, using
468 soil moisture content (e.g., time-domain reflectometry) in conjunction with moisture characteristic curves.
469 Fluid flow (velocity or flux) in and out of wells in saturated media should be monitored using borehole
470 flow meters. Flux through partially saturated media should be inferred using capture-type lysimeters.

471 The number and location of monitoring wells needed to evaluate performance objectives depends upon site
472 conditions. At a minimum, monitoring of performance indicators shall be performed within the surficial
473 (unconfined) aquifer. Where appropriate, additional monitoring within underlying confined aquifers and the
474 overlying vadose zone shall also be performed. Additional monitoring in fractured media or where
475 subsurface voids are present shall be performed if these formations affect flow and transport as defined by
476 the FEPs. The monitoring requirements must meet the necessary compliance as per applicable state and
477 federal standards.

478 At least one multi-level sampling well shall be placed upgradient of the facility to provide local background
479 water quality data. Additional monitoring wells shall be placed downgradient of those components
480 identified in the characterization of operating facilities from which releases may occur. The number and
481 location of the wells should be sufficient to detect significant water-quality changes due to radionuclide
482 releases from those facilities. The design, installation, and maintenance of the monitoring system shall be
483 parsimonious, in that tradeoffs between an increased number of monitoring locations shall be balanced by
484 the need for detailed data collection in each well.

485 The location of these wells shall also consider the location of the compliance boundary and intermediate
486 compliance points. Wells shall be close enough to the components from which a release to the subsurface
487 may occur to assure that contamination is detected while it is still relatively close to its source and
488 manageable. However, wells should not be located so close to structures that their existence interferes with
489 normal operations. Likewise they should not be placed in areas where the surrounding infrastructure
490 interferes with sampling and maintenance.

491 Care shall be taken to assure that plumes do not escape detection by traveling along unmonitored
492 flowpaths. The further the wells are from the facility, the more important it will be to consider the likely
493 vertical trajectory of possible contaminant plumes. In many cases it will be necessary to sample more than

494 one vertical horizon at an individual location. This is most commonly done by installing multiple wells.
495 There are various widely accepted methods for installing multiple, vertically discrete sampling points
496 within a single well.

497 Spatial heterogeneity due to natural geologic conditions (e.g., large voids, fractures, conduits), as well as
498 construction-induced heterogeneities, may introduce substantial uncertainties due to rapid transport in
499 localized regions. Surface and subsurface geophysical techniques are available for characterizing these
500 heterogeneities, including hydraulic, tracer, seismic, and electromagnetic techniques. Monitoring strategies
501 in heterogeneous media shall be justified.

502 Short-duration releases may not be detected if transport is rapid and sufficient temporal sampling resolution
503 is not provided. Automated data-logging capabilities are available for collecting water-level, water-quality,
504 and gas-phase data at selected frequency and precision. These may be connected wirelessly to provide real-
505 time monitoring data capability.

Comment [A38]: ... sampling is not sufficiently frequent. Sampling shall be at short enough intervals to detect brief releases.

506 Engineered barriers may offset the need for additional monitoring locations. The establishment of a no-flow
507 perimeter (i.e., a capture zone) surrounding potential release sites is one method for containing and
508 detecting releases. Appropriately designed and installed extraction wells or vapor-capture systems with
509 ancillary monitoring equipment could provide an early warning system for both water in the saturated zone
510 and tritium vapor in the unsaturated zone, respectively. This system could also be used for corrective action
511 by maintaining positive control if a release is detected. The capture zone should be designed in conjunction
512 with other engineered-barrier and leak-detection systems.

513 **5.3 Data Management**

514 A robust quality assurance / data quality assessment process shall be used to assure that data-quality
515 objectives are met. Quality assurance and control programs shall be used for collected data. Estimates of
516 field and laboratory analytic uncertainties shall be provided. Specification of sampling and analysis
517 protocols should be performed in conjunction with the Performance Assessment paradigm. Data analysis
518 and archival should be key elements in defining data quality objectives. Defense in depth using multiple
519 redundant sampling protocols along with independent monitoring systems should be employed.

520 **Data Quality.** Field monitoring equipment installation and sampling methods should adhere to standard
521 methods as defined by ASTM International (previously known as the American Society for Testing and
522 Materials) and National Ground Water Association guidelines whenever practicable. Data precision can be
523 assessed using field duplicates and laboratory replicates. Data accuracy can be assessed using calibration
524 standards, matrix spikes, and blanks. Data completeness can be assessed by comparing the number of valid
525 measurements with the planned number of analyses. Multivariate statistical analysis of the data can be
526 employed to identify Type I and Type II errors as well as bias corrections.

527 **Data Limitations.** Minimizing data limitations assists in conceptual model development and computer
528 model implementation. Efforts should be taken to quantify and minimize sources of uncertainty including,
529 but not limited to, well construction (e.g., casing integrity, screen locations, inadvertent pathways, grout
530 contamination, insufficient water, etc.) and sampling protocols (e.g., low flow sampling, pumping vs. static
531 monitoring, sample representativeness, etc.).

532 **Geographic Information.** All geographic information shall be geo-referenced, stored in a retrievable
533 electronic format, and presented using a geographic visualization platform. Time-series data shall be stored
534 in a retrievable electronic format and plotted. Statistical characterization, including trend analysis, shall be
535 provided for all performance indicators. Data and information updates shall be performed routinely.

Comment [A39]: Geographic and Time-Series Information

536 **Parameter Databases.** Parameter databases shall be based on a consensus interpretation of the available
537 data. Methods and approaches used to develop the parameter estimates should also be described. The
538 database should include all information necessary to develop parameter distributions based on geologic
539 data (e.g., geometry of the main hydrogeologic units), hydraulic property estimates, boundary conditions,
540 initial conditions, locations and volumes of sources and sinks, and natural recharge estimates. Such a
541 database shall contain the basic geologic and hydrologic information that provides the basis for the
542 conceptual model, as well as the key interpretations of geologic and hydrologic data and information,
543 including descriptions of methods and approaches used to make interpretations. The database and data
544 interpretations shall be updated, as new data on both the local and regional scale become available. The
545 database should be stored in a form independent of the method used to obtain the estimate or the
546 assumptions made for the particular study.

547 **6. Mathematical Modeling**

548 The purpose of mathematical modeling to assist in assessing the performance of groundwater protection
549 programs, which is particularly important at sites where complex hydrogeologic conditions are present, or
550 where uncertainties in the site conceptual model preclude direct interpretation of field data. The ultimate
551 modeling goal is to develop the capability to understand and predict system behavior.

552 An important advantage of simulation modeling is the capability to provide a framework for reconciling the
553 conceptual model with characterization and monitoring data, as well as to provide simulations of system
554 behavior in a timely manner that demonstrate compliance with performance objectives.

555 During the design/permitting stage, model simulations will be an important tool for demonstrating facility
556 safety, with characterization and monitoring data being used to establish model accuracy. During the
557 operational stage, monitoring data will be used to demonstrate the continuing safety of the facility, with
558 model simulations being used to facilitate monitoring data interpretation for circumstances when
559 monitoring data are ambiguous, or do not provide sufficient confidence in system performance.

560 Defining specific model objectives shall be the first step of model development. Possible model objectives
561 include, but are not limited to:

- 562 • Providing an integration tool for documenting and analyzing hydrogeologic processes and
563 assumptions,
- 564 • Reconciling characterization and monitoring data with site conceptual models,
- 565 • Evaluating trends and identifying anomalies or radionuclide releases, and predicting contaminant
566 plume migration,
- 567 • Planning, designing, and evaluating monitoring and remediation strategies,
- 568 • Estimating the effects of facilities on the hydrologic system,
- 569 • Performing radiological exposure assessments.

570 The mathematical model shall consider the physical and chemical processes and parameters relevant to the
571 flow and transport of radionuclides at the site. The level of effort associated with mathematical modeling
572 shall vary with the degree of uncertainty in the underlying conceptual and mathematical model, and the
573 proximity to receptors. The model may range from a simple analytic equation that can be solved manually,
574 to a complex set of differential equations that must be solved numerically.

575 Model scope should address the appropriate features, events, and processes, and shall provide
576 documentation to support the relevant level of model complexity, including as required heterogeneities,
577 scale effects, transient perturbations, etc. It shall also specify the level of model accuracy using a
578 documented process of model testing and evaluation. The analytic or numeric methods for model

Comment [A40]: Insert after:
Operation plans must specify that the model will be updated and compared with monitoring data at regular intervals.

Comment [A41]: The statements before and after this point are by and large replicative.

Comment [A42]: Insert after: Model simulations of individual sets of parameter values ("model runs") shall be documented. Documentation shall be in the form of formal documents or standardized documentation packages to ensure its preservation. Documentation of runs shall include their objectives, input values, results, and interpretation of the results.

579 implementation should be defined for both fluid flow and radionuclide transport. The model selection
580 process shall match relevant processes with code capabilities, data needs with data availability, flow and
581 transport implementations with site conditions.

582 While monitoring data provide important checks on system performance, mathematical modeling is needed
583 to extrapolate observations and to evaluate the adequacy of characterization efforts. This paradigm is
584 iterative and interdependent, in that monitoring data are used to support conceptual and mathematical
585 modeling assumptions, and models are used to identify the scope of monitoring efforts. Assuring that the
586 appropriate conceptual and mathematical models are being used requires the ability to test the model
587 against characterization and monitoring data.

Comment [A43]: "... support and test conceptual ..."

Comment [A44]: "... these models ..."

588 While monitoring is likely to be the primary means for detecting the occurrence and extent of an abnormal
589 release, modeling is another useful tool that can quantify where and how far a release has moved if an
590 abnormal release is suspected. Model predictions are dependent upon the site conceptual model, which may
591 be ambiguous. Thus, an iterative, ongoing effort toward reconciling modeling results with monitoring data
592 is required. Model forecasts should be compared with monitoring data, and vice versa. In essence, one can
593 view the iterative and interdependent process as computer-aided analysis (modeling) that is continuously
594 refined by measurements (monitoring). Additional monitoring locations or characterization activities may
595 be required to distinguish between alternative conceptual models.

596 6.1 Fluid Flow

597 The mathematical model shall reasonably and conservatively simulate groundwater flow as defined by the
598 conceptual model and performance objectives. At a minimum, the model shall be able to accurately
599 simulate water flow in the unconfined aquifer. For more complex systems, additional capabilities may be
600 required to account for liquid, vapor, and gas fluxes in the unsaturated zone, dual porosity through
601 heterogeneous media, or regional flow through confined aquifers and confining layers below the
602 unconfined aquifer.

603 **Spatial Scale of Analysis.** The physical domain of the model shall be established by defining the
604 horizontal and vertical extent and boundary conditions for the model. The model extent should be large
605 enough such that potential onsite and near-boundary receptor locations are included within the model.
606 Incorporation of the lateral extent and thicknesses of the major hydrogeologic units identified in the site
607 conceptual model are necessary to accurately simulate past, present, and future behavior of the subsurface
608 flow and contaminant transport. The model shall also have the capability to represent the major sub-units
609 identified in the major hydrogeologic units. The model extent should also be established based on linkages
610 to performance objectives, existing and proposed monitoring locations, as well as zones where remedial
611 actions are proposed, or are likely should the vadose zone or uppermost aquifer(s) receive contaminants.
612 The model shall be sufficiently detailed such that features that may affect flow and radionuclide transport
613 can be resolved.

614 **Temporal Scale of Analysis.** Flow conditions may change significantly over time due to changing site
615 operations, boundary conditions (recharge, discharge), and land use. The model shall have the capability to
616 effectively simulate flow and contaminant transport on a variety of time scales. The expected simulation
617 period shall be established by defining the historical and predictive simulation periods. The historical
618 simulation periods are used for initial model calibration. Routine predictions are compared against
619 monitoring data. Both the historical and predictive periods shall be consistent with the established model
620 objectives and available data.

621 **Flow Geometry.** While subsurface flow generally occurs in three spatial dimensions, reasonable
622 approximations of flow can be achieved using fewer dimensions in many cases (e.g., horizontal, two-
623 dimensional flow through confined aquifers and vertical one-dimensional fluid flow through aquitards and
624 the unsaturated zone). A justification shall be provided if lower-dimension geometries are used. In highly
625 heterogeneous environments, a dual porosity model may be necessary.

626 **Flow Parameters.** The mathematical model shall incorporate those flow parameters relevant to the
627 conceptual model. The model shall represent the spatial variability of these parameters as determined using
628 characterization and monitoring data. In addition, site-specific components (sources, backfill, geotechnical
629 properties) shall be included, along with the characteristics of natural and induced preferential pathways.

Comment [A45]: Use "artificial fill".
"Backfill" is material used to refill an
excavation, but we may have to deal with
fill placed on the natural ground surface
as well.

630 **Hydrologic Boundaries.** If appropriate, the model shall be capable of incorporating time-dependent and
631 spatially varying Dirichlet (constant head or concentration) and Neumann (fluid or mass flux) boundary
632 conditions. Also if appropriate, the model shall be able to simulate time- and space-dependent sources and
633 sinks of water and contaminants. A head-dependent flux boundary condition may be useful to explore local
634 flow conditions. If appropriate, the model should interface with vadose zone and surface water model(s) by
635 assigning appropriate boundary conditions specifying water and contaminant fluxes.

636 **6.2 Radionuclide Transport**

637 Tritium transport can be assumed to behave as a conservative tracer. Where the transport of other
638 radionuclides and chemical constituents must also be modeled, then additional transport processes shall be
639 included. Where appropriate, the model shall be capable of simulating contaminant fluxes in aqueous,
640 sorbed, vapor, and gaseous phases as a function of driving hydrologic processes and mass-transport
641 phenomena, including advection, diffusion, volatilization, hydrodynamic dispersion (longitudinal and
642 transverse), adsorption, and radiological decay.

Comment [A46]: radioactive

643 **Contaminant Retardation.** If needed to support transport calculations, the model should be able to
644 support simulation of geochemical retardation on a contaminant-specific basis. Use of the linear
645 equilibrium adsorption model would meet the intent of this requirement, but justification of the linear
646 isotherm approach to represent the process of adsorption for specific contaminants shall be necessary. The

647 capability to allow adsorption to vary not only by contaminant, but also spatially (i.e., to be a function of
648 the contaminant and of the hydrogeologic unit in which transport occurs) is desirable.

649 **Dispersion and Molecular Diffusion.** If needed to support transport calculation, the model should be able
650 to support simulation of dispersion and molecular diffusion on a contaminant-specific basis. Use of a
651 constant dispersivity would meet the intent of this requirement, but justification of a constant dispersivity
652 shall be necessary.

653 **Radioactive Decay.** If needed to support transport calculations, the model should be able to simulate the
654 effect of first-order radioactive decay. The capability to simulate first-order radioactive decay is a
655 requirement for the majority of radioactive constituents of concern in predictive contaminant-transport
656 calculations. This capability may also be useful in estimating the effect of chemical degradation if the
657 degradation process can be approximated using this type of decay function. Chain decay is not considered a
658 significant process for most of the mobile radioactive constituents. However, there may be a few instances
659 where the capability to calculate the effect of chain decay in transport simulations would be a desirable
660 feature, particularly in cases where the decay products are more mobile or have greater toxicity than the
661 parent.

662 **Flowpath Modeling.** If needed to support transport calculations, the model shall be capable of efficiently
663 performing streamline (for steady-state conditions) and pathline (for transient conditions) analyses in two
664 and three dimensions. Prediction of contaminant migration requires additional information about the
665 effective porosity and sorption capabilities. A rigorous evaluation of contaminant concentration modeling
666 capabilities requires the use of tracers that more accurately represent likely radionuclide sources.
667 Comparisons of model predictions with monitored concentrations in piezometers and suction lysimeters
668 can be used for model evaluation.

669 **Reactive Transport.** If needed to support transport calculations, reactive transport models should be able
670 to simulate complex contaminant-transport behavior in the vicinity of certain facility and contaminant
671 release locations, yet the use of reactive transport models is not presently viewed as practical because of
672 substantial geochemical data and computational requirements.

Comment [A47]: Add after: "When such models become practicable, their use should be considered in appropriate circumstances."

673 **6.3 Model Management**

674 Multiple computer codes may be required to address all migration pathways of concern. Each code should
675 be fully documented, along with the relationships between codes.

676 **Model Calibration.** A description of the model calibration procedures shall be provided. Calibration data
677 sets and assumptions shall be provided. Differences between model predictions and field observations shall
678 be discussed.

679 **Model Updating.** The conceptual and mathematical model is to be a flexible and evolving platform for
680 analyzing flow and contaminant transport at the site; as more data are collected, it is likely that new

681 predictive capabilities will be desired. The adopted model framework shall be one in which new concepts
682 can be tested and enhancements readily included.

683 **Model and Data Uncertainty.** Uncertainty accounts for those factors that introduce imprecision in model
684 predictions, including geologic variability, measurement error, conceptual model ambiguity, and numerical
685 errors. Uncertainties in the specification of the appropriate conceptual model determine the required scope
686 of characterization, while the evaluation of alternative conceptual models requires characterization data that
687 provide sufficient information for model specification. Additional characterization data are required where
688 numerical model structure is ambiguous, or where model parameters are uncertain. The scope of
689 characterization data collection is a function of the complexity in the geologic environment, along with
690 uncertainty in background conditions.

Comment [A48]: Suggested rewrite:
"Model predictions are imprecise because
of uncertainty about various factors, ..."

Comment [A49]: Clarify that
"characterization" refers to obtaining
enough accurate field data to improve the
model to the extent necessary.

691 **Uncertainty Characterization.** The modeling shall provide for explicit acknowledgement and estimation
692 of uncertainty with respect to the databases, model, and code. Strategies to reduce uncertainties include
693 statistically-based optimization techniques for parameter estimation, sensitivity analyses, and Monte-Carlo
694 simulations. The specification of how uncertainty is incorporated into model development and model-based
695 analyses is also required, especially with regard to how uncertainties will affect monitoring network design,
696 decision criteria, corrective-action strategies, and predictive analyses. Information is needed on how
697 uncertainty is characterized, including its sources and significance, explicit vs. implicit margins of safety, a
698 bounding-approach vs. best-estimate (expected value) approach, use of stochastic (Monte Carlo) methods,
699 etc. Model uncertainties shall be related to model calibration and explicitly linked to decision criteria. ||

Comment [A50]: Identify and
analyze sources of both epistemic
uncertainty – that is, uncertainty about
our actual knowledge - and aleatory
uncertainty – uncertainty due to future
random events. Also, identify risks
associated with uncertainty.

700 **Configuration Control.** The model, including the databases supporting the conceptual model and its
701 numerical implementation, shall be maintained under configuration control. Because the conceptual model
702 will provide the framework for all modeling performed on the site a common model database shall be
703 maintained containing all the information necessary to establish the pedigree of the most current version of
704 the model.

Comment [A51]: computer code?

Comment [A52]: Single? Central?
Unified? The sense seems to be that one
database should be used to track all
variants of the model's computer code
and supporting databases, but not
including the model input data, which
will be tracked separately with
appropriate cross-references to the model
configuration database.

705 **Code Verification.** Evidence of code verification shall be available. The verification provides evidence
706 that the solution methods used in the model are correct and shall demonstrate the effect of the assumptions
707 and potential errors arising from limitations of the model. Verification evidence shall include comparison
708 of model results for a variety of known or accepted solutions. A published history of previous model
709 applications shall exist. Prior applications shall demonstrate that the model is well regarded among the user
710 and regulatory community. In particular, the model shall be acceptable to the EPA, NRC, state and other
711 regulatory bodies.

712 **Model Availability.** The code, along with model inputs and analyses, should be publicly available at a
713 reasonable cost.

Comment [A53]: You need to clarify
whether you are referring to source code
or executable code. Also, where feasible,
models whose source code is publicly
available should be preferred over
proprietary models. This is in part
because rapid changes in computer
technology are almost certain to make
proprietary models unusable within the
life of the nuclear power plant.

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