

GURPS®

Fourth Edition

DISASTERS

MELTDOWN AND FALLOUT™



Written by
ROGER BURTON WEST
Edited by **NIKOLA VRTIS**
Illustrated by **JOHN HARTWELL,**
RAY LUNCEFORD,
and **DAN SMITH**

Additional Material by
S.A. FISHER, MICHAEL HURST,
JASON "PK" LEVINE, KENNETH PETERS,
DAVID L. PULVER, SEAN PUNCH, and
HANS-CHRISTIAN VORTISCH

GURPS System Design ■ **STEVE JACKSON**
GURPS Line Editor ■ **SEAN PUNCH**
Assistant **GURPS** Line Editor ■ **JASON "PK" LEVINE**
GURPS Project Manager ■ **STEVEN MARSH**
Production Artist and Indexer ■ **NIKOLA VRTIS**
GURPS FAQ Maintainer ■
VICKY "MOLOKH" KOLENKO

Chief Executive Officer ■ **PHILIP REED**
Chief Operating Officer ■ **SAMUEL MITSCHKE**
Executive Editor ■ **MIRANDA HORNER**
Marketing Director ■ **RHEA FRIESEN**
Director of Sales ■ **ROSS JEPSON**
Page Design ■ **PHIL REED and JUSTIN DE WITT**
Art Direction and Prepress Checker ■ **NIKKI VRTIS**

Special Thanks: John Dallman, David Damerell, and Phil Masters

Reviewers: Luke Campbell, David Chart, S.A. Fisher, Vicky "Molokh" Kolenko,
Timothy Ponce, Christopher R. Rice, William H. Stoddard, and Antoni Ten Monró

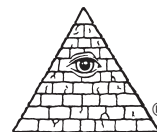
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ABOUT GURPS

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Errata. Everyone makes mistakes, including us – but we do our best to fix our errors. Up-to-date errata pages for all **GURPS** releases, including this book, are available on our website – see above.

Rules and statistics in this book are specifically for the **GURPS Basic Set, Fourth Edition**. Page references that begin with B refer to that book, not this one.

INTRODUCTION

Warning lights flash and sirens sound as temperature gauges go into the red . . . a worried news anchor points at a graphic of a cloud spreading across the country . . . a group of black-clad figures sneaks away, carrying a case marked with warning trefoils . . .

Radiation scares people. You can't see or taste it, but it damages you in a weird and unpleasant way, sometimes years after you thought you were safe. And scary things are good game fodder.

Nuclear accidents make excellent challenges in a modern game. Covert operatives may be sent to sabotage a hostile country's nuclear program, while local engineers and scientists work guard against similar enemy action (as well as genuine accidents). Even people who aren't directly involved with nuclear safety will be affected by the evacuation and panic that follow the mere threat of a major radiation release.

In a science-fiction game, reactors will be safer than they are today, but an isolated spaceship crew still has to worry about radiation in addition to hostile aliens. Maybe they can be used against each other!

Nuclear steam engines might, with a bit of properly timed inspiration, have been built in the 19th century and have kicked off an era of "atomic-punk." In a fantasy setting, a magical contamination could spread like a radiation cloud rather than like the more conventional plague.

Nuclear power is a relatively recent and extremely high-profile invention; *all meltdowns ever* have been documented by the modern media, so details are easy to find. This supplement concentrates on the game aspects rather than on history.

Nuclear-power producers are unsurprisingly cagey about details of their security precautions. All the real-world information in this supplement was obtained from public sources and off-the-record discussions with experts. Nonetheless, when opinions about potential outcomes or protocols differed, this supplement went with the options with more drama or adventure potential.

Nuclear reactors offer many different kinds of adventure possibilities for modern campaigns.

PUBLICATION HISTORY

This is the first edition of **GURPS Disasters: Meltdown and Fallout**. It updates equipment statistics from **GURPS High-Tech** and includes a number of perks from **GURPS Zombies**.

ABOUT THE AUTHOR

Roger Burton West is a British computer system administrator and a product of the wave of roleplaying that swept the United Kingdom in the 1980s. While performing research for this supplement, he received a radiation dose of approximately 30 millirads. His gaming website is at tekeli.li.

GLOSSARY

GURPS Disasters: Meltdown and Fallout uses the following terms and abbreviations.

corium: A lava-like mixture of nuclear fuel, fission products, control equipment, and structural materials from a containment vessel.

criticality: The state in which an ongoing nuclear reaction is self-sustaining. (A reactor that has "gone critical" is operating normally.)

decay heat: Heat generated from natural decay of radioactive substances, rather than from a chain reaction.

exclusion zone: The area around an accident from which civilians have been forcibly evacuated.

fission: The splitting of an atomic nucleus into two or more smaller pieces, often with a release of energy.

isotope: A different form of an element, with the same number of protons but a different number of neutrons; chemically it is similar, but radiologically it can be very different.

meltdown: The melting of a nuclear reactor core as a result of overheating.

passively safe: A reactor which does not require active cooling to prevent a meltdown.

R-bomb: A conventional bomb jacketed with radioactive material, designed to spread contamination over a wide area. Also one of the many devices known as a "dirty bomb."

SCRAM: The process of shutting a reactor down quickly by inserting control rods or other reaction-inhibiting materials. This is often a separate self-contained mechanism from those used in normal operation. Decay heat continues even after this is done.

shake: An informal measure of time, equal to 10^{-8} seconds (10 nanoseconds).

turnkey reactor: A reactor that can be prefabricated, moved to where it's needed, then turned on, rather than one that needs major construction work on-site.

void coefficient: How a reactor's power output changes when liquid coolant develops "voids," or gaps, such as steam bubbles. A large positive or negative void coefficient can lead to a reactor running out of control when voids form or collapse suddenly.

CHAPTER ONE

CORE MELT ACCIDENT

All fission reactors work in essentially the same way. Nuclear fuel decays naturally, one small step at a time. But if an atom's nucleus is hit by a neutron, it can immediately break apart, a process known as *fission*, which throws off neutrons and heat among other things. Some of those neutrons strike other atoms of fuel and provoke them to fission as well; if this happens enough to keep the reaction going, it's known as *criticality*.

The heat given off by the reaction is absorbed by a liquid or gaseous coolant, which itself becomes somewhat radioactive. In a power reactor, that heat is then either exchanged into water, which flashes to steam (the *secondary coolant*, which in theory should not be radioactive at all), or used directly to drive steam turbines to generate torque, which is almost always then fed into generators to produce electricity. The cooler steam from the turbines is condensed back to water (thus the need for a *cooling pond*) and recycled.

Most of the neutrons that are emitted from fission are *fast*; they have high energy and are less likely to be captured by fissile nuclei (instead they are scattered or absorbed by other nuclei). If not enough neutrons cause fission, the reaction won't continue. Slowing the neutrons down to *thermal* energy levels, the process known as moderation, makes them more likely to induce fission elsewhere in the reactor. (This is just one of the counterintuitive things about nuclear power – putting the right substances in the way between fuel rods gives you *more* power.)

Most reactors have a control system based on inserting or removing moderators or neutron absorbers between the fuel elements. (The coolant also has some moderating effect, which can vary; for example, the molecules in steam are more

widely separated than those in water, so it is less effective as a moderator even though it may be flowing through the same pipe.) Control rods consist of a neutron-absorbing material which can be moved into or out of the core to fine-tune the amount of reactivity. However, pushing the control rods all the way in, the so-called SCRAM, doesn't *immediately* shut down the reactor – nor does flooding it with a neutron-absorbing “poison” such as boron. Natural decay heat from various short-lived fission products in the fuel elements will continue to heat the core more than the amount of fuel alone would suggest, even several days after a shutdown. Thus, it's vitally important to keep circulating coolant through the core even after the reactor's been shut down; if that doesn't happen, a meltdown is still possible. Some reactors have independent emergency cooling systems for this.

In most reactors, the bulk of the fuel consists of uranium-238, inert matter which cannot easily be caused to fission; only 3-5% of the fuel is actually fissile uranium-235. (The fuel has already been slightly enriched from the less than 1% found in natural uranium.) For more details on fuel, see *The Fuel Chain*, p. 8.

The nuclear debris left behind in the reactor core after a fission event is often highly radioactive and remains so for decades, even centuries. The neutrons given off can make even normal structural materials radioactive, as well as transmuting normally low-radioactivity uranium isotopes into radioactive transuranics (such as plutonium) that are active for tens of thousands of years.

Accidents take two forms: escape of radioactive materials (coolant or fuel elements), and overheating. For further discussions of accidents, see pp. 9-10, 15.

TYPES OF REACTORS

Although all fission reactors work in *broadly* the same way, a great deal of variation exists between specific designs.

COOLANT

One way to classify fission reactors is the choice of coolant: water (pressurized or boiling; normal “light” water or “heavy” water, deuterium oxide), liquid metal (mercury, sodium, lead, etc.), or gas (helium, carbon dioxide, or nitrogen), with some special and rare exceptions. Water can boil unexpectedly, and

if it escapes can spread quickly. Liquid metals mostly solidify once they're no longer in contact with the reactor, but they're often chemically toxic as well as radioactive. Gas spreads very quickly when it escapes.

MODERATOR

Another decision is the type of moderator: graphite, water (normal “light” water or “heavy” water, deuterium oxide), or some light element such as lithium or beryllium.

Some of these combinations work better than others; if the reactor already uses light or heavy water as a coolant, it makes some sense to use it as a moderator, too. A light-water moderator needs a more enriched fuel (with a higher proportion of fissile materials) than heavy water or graphite (which may be able to run off natural uranium).

Fast reactors do not use a moderator at all; with highly enriched fuel (20% or more uranium-235), they can sustain a chain reaction entirely on fast neutrons. This makes for a smaller reactor size, but there's an obvious concern that fuel for such reactors could be diverted to bombs. A plutonium-based fast reactor can be wrapped in uranium-238, which is then exposed to fast neutrons; this makes a breeder reactor, which turns uranium to plutonium faster than the reactor consumes it, and the surplus can then be run through conventional reactors to generate more power, making the whole system more efficient. (With rather more work, the surplus can instead be used to make nuclear bombs.)

REACTOR TYPES

These choices lead to a variety of actual reactor types, and the problems which can occur with them differ accordingly. This is a representative list of the commoner types in service today, all available at TL7 except as noted.

PWR

Pressurized water reactors – which make up the majority of civil power plants in the West and drive most nuclear-powered ships and submarines – use enriched uranium fuel, with normal water as both coolant and moderator. Primary coolant water leaves the reactor at about 600°F and is kept from boiling by being held under 155 atmospheres of pressure. Secondary steam, fed to the turbines, is at about 530°F and 60 atmospheres. Control rods are held above the reactor core by electromagnets, and they can be dropped into the core even if power is lost. However, high-pressure water needs heavy piping and strong pumps, and is somewhat corrosive. The major non-nuclear hazard is steam leaks.

These have been used primarily in France, Germany, India, Iran, Japan, Russia, the United Kingdom, and the United States.

BWR

The *boiling water reactor* is similar to the PWR, but the primary coolant water is allowed to boil; it goes directly to the steam turbines at about 75 atmospheres and 550°F, with no secondary coolant stage. This makes it rather more efficient than the PWR, but the need for a steam dryer at the top of the reactor (separating mere hot water vapor from useful “dry” gaseous steam) means that control rods must be inserted from underneath, requiring some sort of power supply to shut down the reactor. The liquid-gas phase change in the reactor core also makes control systems more complicated, and sudden unexpected changes in pressure

might break fatigued parts. The turbines become slightly radioactive, though this dies down to a safe level in a few minutes when they're taken off-line. Some of these reactors use graphite moderation, such as the RBMK design (*Reaktor Bolshoy Moshchnosti Kanalnyy*, or High Power Channel-type Reactor) which was at the heart of the Chernobyl disaster. The Fukushima Daiichi reactors used light-water moderation.

These have been used primarily in Germany, India, Russia, and the United States.

CANDU

The *Canada Deuterium-Uranium design* can run on natural uranium (or almost any other nuclear fuel). The design uses pressurized heavy water as a moderator and coolant; it has higher running costs than many light-water designs, but the fuel is easier to obtain. As in a PWR, a secondary coolant loop filled with normal water drives a steam turbine. This is a popular design in Canada and India and has been exported elsewhere.

Nuclear Batteries

Nuclear batteries are not reactors, but they still run off radioactivity; they use the natural decay of a radioactive isotope to generate power. They are less efficient than reactors, but they can be built much smaller. The batteries can be made simple enough to run for 10-20 years without supervision even at TL7. The best known is probably the *radioisotope thermoelectric generator* (RTG), which uses the nuclear heat to warm up one end of a thermocouple, with the other end left in a cooling pond or other heat sink; the temperature differential produces power. Other systems use different ways of converting nuclear activity to power: thermovoltaic cells, alkali-metal thermal-electric converters, and even small Stirling-cycle engines. RTGs have been installed in many unmanned and manned spacecraft including the Pioneer, Apollo, Viking, and Cassini missions, as well as a chain of unmanned Soviet lighthouses and navigation beacons above the Arctic Circle. (The lighthouses have now run down and, in some cases, apparently have been stripped for other valuable metals.) The most common fuel is plutonium-238, with a radioactivity of around 290 TBq per lb.; satellites have carried RTGs with initial activity of around 500-2,000 TBq (see *Measuring Radiation*, p. 7).

TRIGA

Around 70 reactors with the *training, research, isotopes production* – *General Atomic design* have been installed around the world. They ran originally on highly enriched uranium (on low-enriched uranium since the 1970s) immersed in a pool of cooling water. They do not need containment buildings, and they are designed to reduce power output automatically as temperature increases, making meltdowns very unlikely. These reactors do not produce useful amounts of power. Rather, universities and hospitals use them for research and irradiation.

These have been used primarily in Germany, Japan, and the United States.

CANDU is the most efficient of all reactors in using uranium: it uses about 15% less uranium than a pressurized water reactor for each megawatt of electricity produced.

– CANDU Owner' Group Inc., "CANDU Reactors"

Magnox and AGR

The British nuclear power industry developed the Magnox reactor and its successor, the advanced gas-cooled reactor, for domestic use. These use natural (*Magnox*) or enriched (*AGR*) uranium as the fuel, graphite as the moderator, and carbon dioxide gas as the coolant, with a secondary steam loop. Early Magnox designs were built to produce plutonium for nuclear weapons, with power as a convenient side effect. Loss of coolant isn't as severe a problem as with the water-cooled reactors, since in an emergency, air can be pumped through the core and works nearly as well as carbon dioxide, and power runaways can't boil a coolant that's already in gaseous form. However, if the shutdown process fails for any reason, a meltdown is still possible.

The Magnox design has been used primarily in Italy, Japan and North Korea, while AGRs have only been built in the United Kingdom.

Liquid Metal

Liquid metal has been used as a coolant in some fast reactors. These reactors use highly enriched fuel, and since liquid metal can carry much more heat than water or gas, they can be built very small. The power plants on Soviet "Alfa" (Project 705) attack submarines used a lead-bismuth coolant to generate high power for their 40-knot sprint speed.

Unlike water, liquid metals can be moved by electromagnetic pumps, with no moving parts. However, the entire reactor core is permanently submerged in molten metal, which can never be allowed to solidify. Additionally, one type of coolant, a sodium-potassium mix, while excellent for the job in many respects, will ignite violently on contact with water.

These have been used primarily in France, Germany, India, Japan, Russia, the United Kingdom, and the United States.

Turnkey Reactors

With the advance of computerized control systems at TL8, some recent effort has gone into small *turnkey* or *small modular* reactors, producing about 10-100 MW rather than the 500-2000 MW of conventional designs. These are intended to be shipped preassembled and set up in sites away from a power grid – Antarctic bases, developing countries, even disaster zones – and then run with little or no maintenance until they are refueled or retired. The Toshiba 4S and the American SSTAR from LLNL are both liquid-sodium fast breeder designs (to keep the size down); they are expected to run for 20-30 years without needing refueling or major maintenance

(though the SSTAR could incorporate a remote shutdown command in case its host country does something unacceptable). The NuScale SMR and Babcock & Wilcox mPower are light-water designs which can keep the core cooled by convection, without the need for pumps. Many of these designs use unconventional approaches to keep size down and assure safety even in the case of a massive systems failure.

No turnkey reactors are in use yet.

The Future

Several designs are being developed or considered for the future (TL8, though improvements may continue into TL9).

The *very high temperature reactor* (VHTR) uses helium or a molten salt as the coolant and graphite as a moderator in a pebble-bed core (tennis-ball-sized fuel "pebbles" which can be fed in and out of the reactor by gravity). This design is passively safe (it won't melt down if cooling fails), and it can produce high temperatures for local use (e.g. process heat for a chemical plant).

The *molten-salt reactor* (MSR) has nuclear fuel dissolved in uranium or thorium tetrafluoride, which also serves as the coolant, flowing through a graphite moderator. (Some variants have the fuel embedded in the core but retain the molten salt coolant.) Like liquid-metal coolant designs, this can be made quite small; unlike them, the salt can be allowed to freeze when the reactor is shut down, and thawed out later.

The *supercritical water reactor* (SCWR) takes many of the features of BWR and PWR but uses hot, high-pressure water/steam as the coolant; it can operate at much higher temperatures than the other types, but the coolant presents an extreme scalding hazard.

The *gas-cooled fast reactor* (GFR) is a development of the VHTR concept, using helium coolant, highly enriched fuel, and no moderation, for high temperatures and efficiencies.

The *sodium-cooled fast reactor* (SFR) and the *lead-cooled fast reactor* (LFR) develop the liquid-metal breeder design. The SFR allows any transuranic isotope to be used for fuel, including the waste products of other reactors. The LFR replaces reactive sodium with relatively inert lead-bismuth alloy.

Thorium-232 offers some potential as a fuel, particularly in VHTRs and MSR. It is more readily available than uranium and more stable at high temperatures, and the decay products are less readily made into nuclear weapons. However, fuel fabrication is more difficult (other fissile material needs to be mixed into the fuel to start things off), and the waste is more active for longer than with a uranium-fueled reactor.

TYPES OF RADIATION

Nuclear radiation comes in five main forms: alpha, beta, gamma, X-rays, and neutrons, which for game purposes are considered as a single radiation dose. Consult the *Typical Radiation Dose Table* (below) to see how much radiation a person could get from various sources (under “Dose”), including how long it would take to receive one rad from those sources (under “Time/1 Rad”).

PROTECTION FROM RADIATION

Alpha and beta particles can be stopped even by thin clothing; their sources are only harmful if they enter the body, for example by inhalation or consumption, or if beta particles strike unprotected skin. For the same reason, they don’t go far even through air. Gamma radiation is much more penetrating, sometimes passing through several centimeters of steel before interacting with something. Gamma and X-ray radiation are mostly stopped by high density and high atomic number; lead is favored as having a useful combination of both.

Neutrons are harder to predict. They pass readily through many materials, but are slowed and scattered by light elements such as hydrogen, so large masses of polythene, paraffin wax, and water are good shields. The best shield of all is polythene impregnated with boron, which captures the low-energy neutrons that have been slowed by the hydrogen.

MEASURING RADIATION

The total activity of a mass of radioactive substance, which gives a good idea of the scope of a disaster, is measured in becquerels (Bq): one Bq is one decay event per second. This is an inconveniently small unit, and the gigabecquerel (GBq, 10^9 Bq), terabecquerel (TBq, 1,000 GBq or 10^{12} Bq), petabecquerel (PBq, 1,000 TBq or 10^{15} Bq) and even exabecquerel (EBq, 1,000 PBq or 10^{18} Bq) are more often used. The curie (Ci) is found in older material; one Ci = 37 GBq.

The amount of radiation absorbed by something, in terms of energy per mass, is measured in grays (Gy) or rads; one Gy = 100 rad. This is what *GURPS* uses to determine how much an individual is damaged by radiation. No simple relationship exists between becquerels and rads.

Not all energy is equal in its capacity to do biological damage, and for anyone who is getting painstaking about it, the health effects of a dose are measured in sieverts (Sv) or rem (röntgen equivalent man); one Sv = 100 rem. Generally, these are used for small doses, where the important concern is the odds of getting cancer many years down the line rather than anything more immediate. *Very roughly*, take a dose of one rem as being about one rad.

Typical Radiation Dose Table

Source	Dose	Time/1 Rad	Notes
Nuclear Power Plant Annual Release	3 millirad/year	300 years	
Average Yearly Background Dose	300-600 millirad/year	2-3 years	
Chernobyl Grounds in 2014	14 millirad/day	2 months	
Cosmic Rays	1 rad/week	1 week	[1]
Jovian Radiation Belt at Callisto	10 millirad/hour	4 days	[2]
Non-Lifesaving Emergency Worker Limit	10 rad/incident (multiple days)	–	
Van Allen Belt	100 millirad/hour	10 hours	[2]
Fukushima Daiichi Workers	18 rad/incident (multiple days)	5 hours	
Lifesaving Emergency Worker Limit	25 rad/incident (multiple days)	–	
Chest X-Ray	2 millirad/session	40 minutes	[3]
Chest CT Scan	700 millirad/session	30 minutes	[3]
Small Solar Flare at 1 AU	10 rad/incident (1-3 hours)	5-20 minutes	[2]
Dental X-Ray	15 millirad/full mouth series	5 minutes	[3]
Mammogram	40 millirad/session	2 minutes	[3]
Medium Solar Flare at 1 AU	200-1,200 rad/incident (1-3 hours)	5-60 seconds	[2]
Jovian Radiation Belt at Ganymede	600 rad/hour	6 seconds	[2]
Large Solar Flare at 1 AU	2,000-6,000 rad/incident (1-3 hours)	1-5 seconds	[2]
Jovian Radiation Belt at Io	3,600 rad/hour	1 second	[2]
Jovian Radiation Belt at Thebes	18,000 rad/hour	0.2 second	[2]
Chernobyl Core After Meltdown	500 rad/minute	0.1 second	
Hiroshima Atomic Bomb at 0.8 miles	600 rad (during event)	–	

Notes

[1] This is extremely penetrating radiation. Divide PF by 100 before applying.

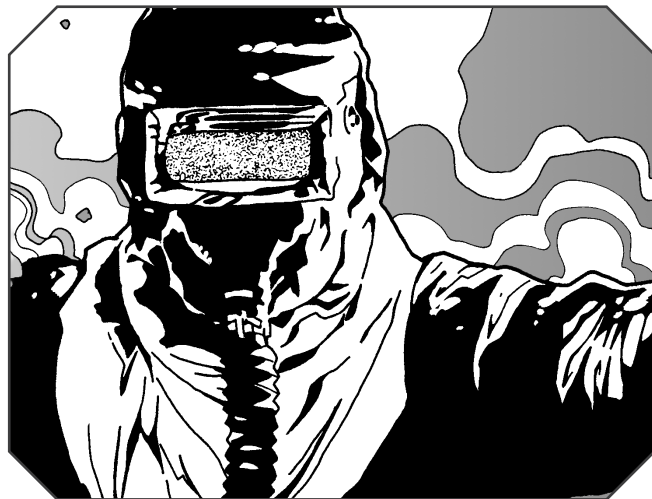
[2] This is not particularly penetrating radiation. Multiply PF by 20 before applying.

[3] “Time/1 rad” value is for a machine running continuously; medical devices operate for only a few seconds at a time.

However, neutrons induce radioactive decay in the nuclei they hit, for example, producing gamma radiation; something that's undergone neutron irradiation often becomes a mild radioactive source itself. Neutrons also tend to make solid materials brittle and prone to crack.

A full radiation shield has boronated polythene or water outside a more conventional lead layer. If it's to be exposed to a lot of high-energy radiation, an iron layer closest to the radiation source will help slow neutrons further, though it must be replaced often.

The *Radiation Protection Table* (below) gives updated values for the thickness required for a Protection Factor (PF) of 10, and the PF per inch of particularly useful materials. Multiply



together the PF value for each inch of shielding to get the total PF: 2" of lead has 6×6 , or PF 36. For more information on radiation protection, see p. B436.

Once radiation has got through all available protection to affect living beings, see *Effects of Radiation* (pp. 16-17) for details on what happens next.

Radiation Protection Table

<i>Material</i>	<i>PF 10</i>	<i>PF/inch</i>
Osmium	0.7"	23
Iridium	0.7"	23
Uranium	0.8"	19
Gold	0.8"	16
Tantalum	1.0"	10
Thorium	1.3"	6
Lead	1.3"	6
Bismuth	1.6"	4
Concrete	1.9"-8.0"	0-3
Tin	3.0"	2
Steel	3.3"	2
Copper	3.5"	2
Carbon steel	4.4"-5"	2
Packed soil	1'	*
Loose soil	2'	*
AL-356	2'	*
Aluminum	2'	*
Water	2'-7'	*
Lumber	3'	*
Air	0.5-1 mi	*

* The PF is less than 2 per inch, too low to be relevant.

THE FUEL CHAIN

Natural uranium is mined, milled, and then usually enriched, separating out the reactive uranium-235 (less than 1% as found in nature) from the less useful uranium-238. This process is costly and difficult, usually done with cascades of gas centrifuges that separate the very slightly lighter isotopes from the very slightly heavier isotopes. Bringing the uranium-235 up to about 3-4% of the total is enough to use it in a light-water reactor. Fast reactors require about 20-40% ("highly enriched"), while nuclear bombs reach 85% ("weapons grade"); some American submarine reactors have used 50-90%. Leftover uranium-238 is *depleted uranium*, used in armor, armor-piercing rounds, and radiation shielding.

Enriched uranium for power reactors is milled into pellets and sealed into fuel rods of a size matching the reactor in which they'll be used; they're clad in a zirconium alloy, or occasionally steel, then clustered together into bundles about 4" across for ease of handling. These are transported to the reactor site and loaded into the core, typically during a shutdown for refueling, though some designs – including the CANDU and the RBMK – allow refueling "on-load." Some reactors, particularly modern naval ones, are "full-life" designs, intended to last the service life of the vessel without being refueled; refueling a submarine's reactor means cutting the hull apart.

The power from a fuel rod gradually drops as the uranium-235 is used up; normally, an individual fuel rod is replaced after one to two years. After removal, it is stored in a spent fuel pool, under about 40' of water; this may be done on site at the reactor or at a dedicated storage facility. The spent fuel is still highly radioactive and hot; the pool allows short-lived fission products to decay safely, and it provides temperature and radiation shielding. Heat exchangers keep the water in the pool from boiling.

The fuel may remain here for years; typically after 10-20 years, it is removed and taken for reprocessing or long-term storage. (The United States does not reprocess spent nuclear fuel, largely for political reasons, but large amounts are shipped between Europe and Japan.) Reprocessing breaks down the fuel, removes the fission byproducts, and feeds remaining uranium (as well as plutonium and other radioactive substances, depending on the reactor design) back into the enrichment cycle for use in new fuel rods.

Any radioactive substances that cannot be used must be stored out of harm's way. Most of them decay within a few months or years, but transuranic elements can remain "hot" for thousands of years. Current plans call for storage deep underground, in geologically stable areas. (If fuel is not reprocessed, all the byproducts stay mixed together, and *everything* has to be treated like the transuranics.)

ECONOMICS AND POLITICS

Nuclear power costs more than power from coal, oil, gas, or hydroelectric plants, but much less than power from solar, wind, or wave sources. That's a rough estimate; costs of wind and solar are dropping, and opinions differ. Nuclear plants must have waste disposal included in their costs, and fossil-fuel ones don't, but the byproducts (pollution) from fossil-fuel power are arguably much more damaging than the worst plausible reactor accident would be. France, generating 75-80% of its electricity from nuclear power, has the cheapest electricity in Europe and sells a great deal of it to other countries.

Nuclear power research was spurred in the 1970s after the oil-price shocks, but it has rather languished since, with politicians unwilling to take on anti-nuclear activists for distinctly arguable gains. Following events in Fukushima, Germany decided to eliminate nuclear power, and France is scaling down its commitment. Japan shut down its reactors without making a formal policy decision, though as of 2015, it is starting to put some back in service. The United States is now extracting enough oil and gas within its borders that being held hostage by foreign oil sellers is no longer a major concern.

NUCLEAR MYTHS

Even though radiation is still a fairly new idea, there's been plenty of time for mythology to grow up around it.

When radioactivity was newly discovered (from 1896), this powerful force was used in much the same way that electricity had been a few years earlier, by quack physicians (and even some genuine-but-misguided ones) as a healing tool – radium pendants to cure rheumatism, natural radon water to increase vigor, uranium blankets to treat arthritis and so on. Many of these were fakes, of course, but the ones which did provide a genuine radioactive dose (such as the radium-thorium tonic Radithor) were often fatal to heavy users. “Doramad” radioactive toothpaste was produced in Germany during the Second World War, but radiation cures gradually fell out of favor in the United States during the 1930s. A few such products are even still on the market today, largely in Japan, though consumer-protection laws prevent them from having actual harmful content. It's rumored that some people

have even tried to gain superpowers by irradiating themselves, with predictably dismal results (but see *Superhero Origin Stories*, pp. 13-14).

“Red mercury” appeared in the 1980s, generally presented as a Soviet secret available at a very low price (for cash only). Depending on the seller, it could make uranium enrichment much faster; be a powerful “ballotechnic” substance (similar to an explosive, but producing vast amounts of heat rather than pressure) which could trigger a pure fusion bomb “the size of a softball” without the need for a bulky fission first stage; or be the superconducting secret of radar-invisible “stealth” vehicles or missile guidance systems. Actual samples recovered from supposed sellers have been a variety of inert red-colored powders. Of course, that may just be what *they* want you to think. For more on this, see “Eidetic Memory: Red Science” in *Pyramid* #3/46: *Weird Science*.

CAUSES AND EVOLUTIONS OF PROBLEMS

The primary cause of reactor accidents is optimism. Pipes become corroded; maintenance is underspecified or not carried out correctly; warning signs are ignored because commercial pressure requires full operation at all times. But external factors also can cause problems: a plane can crash into the reactor (though containment buildings are already specified to withstand that); an earthquake, tornado, or tsunami can hit the site; or terrorists could target it.

Any nuclear facility is likely to have large tanks of chemicals for various technical purposes; for example, chlorine, propane, sulfuric acid, and ammonia have all been used at British AGRs. Those tanks need to be refilled periodically, and chemical spills are a concern.

A secondary coolant leak is probably more dangerous from the steam and hot water than because of the radiation. Primary coolant is even hotter, but also highly radioactive. If

enough of it gets out, the reactor core is more likely to overheat and melt. Should the core itself become damaged, raw fuel and decay products would get out; these are sufficiently hot to melt the structural materials of the core and start burning their way down through the concrete foundations.

If any radiation leaks are combined with structural damage (perhaps from steam or hydrogen mixing with oxygen and causing explosions, from chemical leaks corroding or exploding protective barriers, or from energetic weather effects), even solid contamination can be scattered well beyond the boundaries of the power plant. The “R-bomb,” a type of dirty bomb which wraps a conventional explosive core in a jacket of highly radioactive material, works in a similar manner. Fires in fuel or bomb-assembly plants can spread a great deal of contamination; a single fire at the Rocky Flats nuclear weapons plant in 1957 released around one TBq of plutonium.

Accidental nuclear explosions are strictly cinematic, because they're surprisingly difficult to produce. If the GM wants nuclear explosions with a tissue of plausibility, set them in bomb-assembly facilities, which might be colocated with the power plants that produce the bombs' fuel; it's easier to explain away any radiation that way. Even then, accidents are unlikely because everyone involved knows just how dangerous this stuff is, but a saboteur might well manage to arrange for an electrical test to set off a warhead.

Outside the immediate area of a reactor plant, nuclear fuel and waste have to be transported; they're always heavily

*Now, I don't want to alarm anybody . . .
but we've had some radioactive steam released
into the air from the nuke plant over the hill.*

– *Berkeley Breathed, Bloom County*

guarded, and armored against plausible accidents, but a convoy on the move may still be a more tempting target for bad guys than a fixed installation.

SCALE, EFFECTS, AND AFTERMATH

The size of a nuclear accident can be anything the plot demands. At the bottom end, a minor release of slightly radioactive water wouldn't cause much damage, but it's still enough to get someone fired. At the top end, the accident could release enough contamination into the atmosphere to depopulate a medium-sized country.

CASUALTIES

If a core is breached, anyone working in the reactor building has certainly taken a fatal radiation dose of 4,000+ rads.

Those anywhere else on the site are in trouble if they don't evacuate upwind immediately. Plant workers, rescue personnel, and heroic player characters may feel the need to stick around and stop the disaster from getting worse, but they may be quite literally giving up their lives to save others. A modern population will start to notice that they're getting ill within a few hours, but they can be evacuated from the immediate area before they've taken a fatal radiation dose as long as the process begins immediately (no waiting several days in the hope that things aren't as bad as they look), and panic or disruption do not slow the evacuation down.

ULTRA-TECH MELTDOWNS

Nobody has yet built a commercially viable fusion reactor, but they should be safer than fission plants. Given how difficult it is to get the fusion process started, and since all current designs rely on a steady external supply of fuel rather than building the fuel into the reactor core, it seems likely that any accidents will cause a shutdown, and the decay heat problem of fission systems doesn't occur with fusion. A fusion-reactor problem may involve a local release of heat, as well as short-lived radioactive fuel and byproducts, but this is an industrial accident rather than a disaster; the scope is unlikely to reach far beyond the reactor site. The main hazard will be burning damage with the radiation modifier; a reactor core might do 6d×800 per second, though it would shut down and begin to cool off as soon as it was interfered with. Most of the isotopes that may be released are very short-lived, so contamination isn't a major concern; the exception is tritium gas, which spreads out very quickly in the atmosphere.

Antimatter reactors don't have that level of safety; the fuel alone is dangerous. According to models, antimatter exposed to normal matter probably fizzles over several seconds or minutes rather than detonating like a nuclear weapon, since the heat of annihilation pushes the reacting surfaces apart. However, it still produces a great deal of heat and gamma radiation, and no practical way currently exists to stop it until the material is used up.

Cinematic ultra-tech meltdowns follow a simpler rule: the more power, the bigger the bang. Once you rupture the cooling system, you're on a one-way ride to thermonuclear explosion. Higher technology *does* let you predict the time of the explosion more accurately, so you know when to stop trying to fix it and start running.

PHYSICAL DEVASTATION

Even if the core is breached, the visible damage is often minimal: one destroyed building, some fires, and maybe some damage to structures nearby (see *Core Breach!*, p. 15, for details). The effect on the environment takes longer to become apparent: Plants and animals sicken and die in a swath downwind of the site, and detectable contamination spreads for thousands of miles.

SOCIAL AND ECONOMIC IMPACT

Nuclear power plants are generally safe and reliable. When one is shut down suddenly, there may not be enough other power sources to carry the load, especially if multiple plants on a site are shut down at once because of a larger disaster. More capacity may be available elsewhere in the grid, but the transmission system will be worked harder than usual. This can cause cascade failures in transformers and power lines; electricity is cut to the general populace, and the plant itself may be reliant on batteries during its emergency procedures. A lack of power not only impedes rescue efforts but knocks out almost all the ways people stay informed (many cell towers only have enough battery power to last a few hours), and they become more likely to panic at the news that does reach them.

CHAPTER TWO

GAMING A MELTDOWN

A meltdown or other nuclear accident happens in phases: before things go wrong, with sabotage, creeping failures, and prevention; during the accident itself, which is generally over in a few minutes or hours, though complications and

secondary problems can continue for days; and the aftermath, which includes control of the release, remediation of damage, and getting clear of the danger zone.

CHARACTERS

The best way to avoid adverse health outcomes from radiation is to stay away from the hot zone. If that's not an option, the right advantages and skills will definitely help. These can be added to existing templates or lenses to reflect the occupations of those who work around radiation.

ADVANTAGES

Unfortunately, normal humans' response to radiation is not subject to any great variation. All of these advantages are exotic and not appropriate for realistic campaigns.

Doesn't Breathe

see p. B49

You may ignore the *entire* radiation dose from gases, and subtract 50% of the remaining dose rate from a typical contaminated area, as you are not inhaling particles.

Filter Lungs

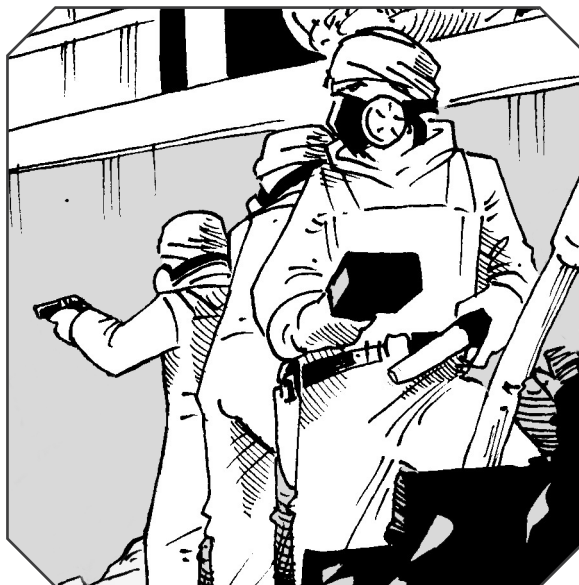
see p. B55

You may subtract 20% of the dose rate from a typical contaminated area, though the filtered particles are still inside your body, so some damage is still being done.

Radiation Tolerance

see p. B79

Although this is unrealistic for humans, it is entirely appropriate as a racial advantage for nonmammalian characters.



Regeneration

see p. B80

Note that the standard version does not heal radiation damage at all, but Heals Radiation and Radiation Only are available as modifiers.

Resistant

see pp. B80-81

Radiation is a "Rare" hazard and is included in the category of Metabolic Hazards. This advantage adds to or removes the need for HT rolls against radiation damage (see *Radiation*, pp. B435-436).

Immunity removes the need for most HT rolls, though even that does not give total protection: For 21-800 rads, apply class A effects. For 801-4,000 rads, apply class B. For 4,000+ rads, apply class C. (See the *Radiation Effects Table*, p. B436, for details on results.)

Resistant and Immunity do nothing against effects which are not resisted by HT rolls, such as being cooked by extreme heat or embrittled by neutron bombardment (see *Radiation Damage to Exotic People*, p. 16).

Electromagnetic pulse (EMP) is also a "Rare" hazard; see *Three Shakes* (p. 15) for details on this danger.

Sealed

see p. B82

You may subtract 30% of the dose rate from a typical contaminated area. (Particulates don't lodge on your body.)

PERKS

Some people just have a knack for working in bulky protective gear.

Hot-Zone Hero/Heroine

Prerequisites: Hazardous Materials (any) and NBC Suit at 16+.

You're exempt from *routine* skill rolls to don or decontaminate hazmat gear: masks, suits, etc. This has no effect on extraordinary uses or on rolls to handle dangerous stuff rather than to suit up.

NBC Suit Experience

NBC Suit skill (p. B192) doesn't limit your DX or DX-based skills when wearing hazard gear that isn't bulky enough to give at least -1 to DX.

Standard Operating Procedure

Each SOP perk exempts you from having to tell the GM that your PC is doing one particular thing that's second nature for him. You always enjoy the benefit of the doubt. This doesn't give you the material resources your perk needs – it just means that if you have those resources, you use them.

Badge Checker: You're always keeping an eye on any radiation counter you have access to. You'll never be taken by surprise when a previously safe area turns "hot," even if it's a very slow change.

Clean Freak: If there's clean water, you wash. If there's soap, you use it. If there was a chance to decontaminate your gear safely, you did it. You'll always qualify for any small bonus to HT rolls vs. contamination from such measures.

*At every stage of this disaster,
which came within moments of being
a far greater disaster, the officers and
crew did what had to be done.*

*– Mikhail Polenin,
in K-19: The Widowmaker*

DISADVANTAGES

To some people, safety standards are more than just a way of life. To others, all radiation is to be feared.

Code of Honor

see p. B127

Many reasonable people working in the industry have an informal Code of Honor to protect the public – it's something of a cultural standard. Because the consequences of a major radiation release are so dire, anyone with this disadvantage feels that extreme measures, most definitely including self-sacrifice, are justified to prevent one. These are the

divers who went into the reserve water pond under the Chernobyl reactor to drain it and prevent a massive steam explosion, knowing they'd take a fatal dose in the process, or the control room operator who stayed at his post to try to lower control rods while staring into the reactor core. Code of Honor (Professional) most readily represents this extreme reaction in a rare situation. -5 points.

Delusions

see p. B130

Radiation hormesis is a hypothesis that has had at least some mainstream support, though little current evidence supports it. A believer would have the Minor Delusion "Radiation is good for you, at least in moderate doses."

Phobias

see pp. B148-B150

Radiophobia is the abnormal fear of all ionizing radiation. You will never accept a medical X-ray or take a long-distance flight, and you certainly won't work in the nuclear industry or live near a nuclear plant; you will react badly to people who do (they're probably contaminated already). -5 points.*

QUIRKS

People who work around radiation can develop some peculiar habits. Many existing disadvantages can be turned into quirk-level versions that are specific to radiation, such as Cowardice ("that stuff scares me"), Honesty ("these rules are here for a reason"), Overconfidence ("never did me any harm"), and even Unluckiness ("oops").

Always Jokes About Radiation

You can act seriously enough, but you talk about radiation as a laughing matter, perhaps to hide your fear of it. Others react to you at -1 when this quirk becomes apparent. While you still follow normal procedures, you are at -1 to spot any mishaps.

No Sense of Humor About Radiation

You can have normal social interactions on most subjects, but when it comes to radiation, you never joke, and you always discuss the subject with deadly seriousness. Others react to you at -2 when this quirk becomes apparent, but your friends learn not to bring it up.

SKILLS

Several existing **GURPS** skills and specialties cover nuclear operations and cleanup procedures.

Electronics Operation (Scientific)

see p. B189

This is the ability to operate radiation-measuring instruments, including reconfiguring multi-mode counters. Failure provides incorrect data; e.g., you read the wrong scale of an analog unit and believe the radiation rate to be orders of magnitude higher or lower than it really is.

Engineer (Nuclear)

see pp. B190-191

This is the skill of designing nuclear batteries, reactors, and warheads, using fusion, fission, or natural radioactive decay. *Prerequisite:* Physics. *Default:* Mechanic (Fission or Fusion Reactor)-6.

Hazardous Materials (Radioactive)

see p. B199

This skill covers the use of hot-zone equipment other than personal protective gear: sealed vehicles, basic operation of radiation-measuring instruments, dosimeters, decontamination showers, and so on. It also covers complete knowledge of containment facilities and cleanup protocols for radioactive waste and fallout.

Mechanic (Fission Reactor)

see p. B207

This skill deals with the maintenance and repair of fission reactors, from tweaks to the control inputs during a normal day to knowing which valves to close when things go horribly wrong. It also includes maintenance and repair of steam turbines.

Some people, particularly those who work with them all the time, are likely to have Hyper-Specialization (*GURPS Power-Ups 2: Perks*, p. 16), for +5 to fix a *specific* reactor design: British AGR, Soviet RBMK, U.S. General Electric BWR/4. (See pp. 5-6 for overviews of different types of reactors.)

NBC Suit

see p. B192

Everyone working around radiation has a point in this skill – donning a suit and ensuring it is sealed, and removing it without transferring outside contamination into a clean area, are both complex and multistage processes. If you're running buddy checks, a failure just means you have to take the time to do it right, and a critical failure indicates contamination; if operating solo, any failure risks contamination.

Physics (Nuclear)

see p. B213

This optional specialty of Physics skill covers the science of nuclear decay, fission, and fusion processes. Anyone who has spent a point in this skill is also familiar with the operation of radiological measurement gear. This is an *optional* specialty, so general Physics skill also gives these benefits – but most physicists specialize. Indeed, most realistic physicists will have Hyper-Specialization (*Power-Ups 2*, p. 16), for +5 in a particular, narrowly defined area.

Given a list of isotopes present at a radiological hazard site, a Physics (Nuclear) roll can tell you more about the event: how long ago did the release happen; what was the original composition; was it from a bomb, a reactor, or something else?

Survival (Radioactive Wasteland)

see pp. B223-224

You know the signs of extreme radioactive contamination in plants and animals, and how fallout tends to move in wind and water. Even if you don't have instruments, you can roll to spot and avoid areas that are likely to contain intense radiation. If the underlying terrain type is still readily recognizable (such as the Chernobyl exclusion zone, which is Woodland), you can roll first against the appropriate Survival specialty to recognize the symptoms of localized environmental damage; a success gives +1 to this skill, a critical success gives +3, and a critical failure gives -1. Also, if you have rolled against another Survival specialty first, you can use Hazardous Materials (Radioactive) in place of this skill, with the same bonuses or penalties. If you are so foolhardy as to scavenge for food, you need to roll against both this skill and the other Survival specialty to avoid picking something tasty but radioactive or radiologically inert but poisonous. But if you're somewhere like an area that's been nuked to bedrock, or the shores of Lake Karachay (600 rads/hour), so heavily contaminated that no normal life remains, this skill is the only thing you can use to avoid problems, and you have no chance of finding food.

For more on survival in an irradiated wasteland, see *GURPS After the End 2: The New World*.

CINEMATIC MUTATIONS

Cinematic mutants are mostly distinguished by their fangs, claws, and hunger for humans. To give this a little plausibility, metabolic pathways might be damaged so that some vital enzyme or hormone is no longer synthesized – the only way to stay alive is to consume the uncooked flesh of specific organs (or inject the blood) of a similar species. See *Weird Radioactive Disasters* (pp. 24-25) for further ideas.

Even more cinematically, creatures may gain traits of other species (venom, acute senses, a hard carapace), other powers like Stretching, or – at the extreme end – powers related to radiation: immunity to further harm from radiation, a bite that does a radiation dose as well as the usual damage, or even a “radioactive glow” that exposes anyone who gets too close. *GURPS After the End 1: Wastelanders*, *GURPS Powers*, *GURPS Supers*, and “Are We Not Men?” in *Pyramid* #3/90: *After the End* suggest traits for mutation-based characters.

Superhero Origin Stories

*Is he strong? Listen bud –
He's got radioactive blood!*

– *Spider-Man* (television theme song)

Movies and comics have been enamored with the mutation-inducing effects of radiation, without showing much grasp of what that means in practice. With animals (such as the ants of *Them!* or the reawakened dinosaur of *Godzilla*), the effects have mostly been much greater size and increased ferocity, but humans sometimes have experienced more complex results, including superpowers.

Throughout the history of superhero comics, many people have gained their powers through scientific accidents – and in many cases, “radiation” was involved, in some usually ill-defined way. This may have reached its height in Marvel comics in the 1960s, in which Bruce Banner became the Incredible Hulk after exposure to radiation from a “gamma bomb” (and many of his opponents had their own experiences with radiation), while Spider-Man gained his powers through being bitten by an irradiated spider. The mutant X-Men carried the subtitle “Children of the Atom” for a while, and several of their parents were explicitly noted as having worked with or been exposed to radioactive material. The Fantastic Four were exposed to “cosmic rays” on a space mission.

This has become less common in recent years, as other scientific phenomena have become more popular, and writers and readers have perhaps become more aware of the realities of radiation. Recent versions of Spider-Man have replaced the irradiated spider with a nanotech-infused or genetically modified creature.

However, science in superhero comics is frustratingly bad at producing reproducible results – and attempts to re-create power-inducing accidents, with or without radiation, are rarely successful. In fact, comics often show *deliberate* abuse of radiation as leading to more-or-less realistic results, including sickness, cancer, and death. Hence, even a supers game in the style of classic comics can employ most or all of the rules given in this supplement for radiation effects – except when PC heroes and NPC supers are directly involved. In these cases, radiation can have whatever plot-helpful consequences the GM might like (including realistic tragedies). Likewise, any time someone with the Origins Magnet disadvantage (**GURPS Supers**, p. 32) wanders into a radiation research laboratory, things can get weird.

A PC who has points set aside for a potential advantage (p. B33) might invoke them for a form of one-off radiation resistance. Perhaps each character point stored this way lets the person ignore 10 rads, once only, and immediately convert all those points into random powers.

Question: [Would it be fatal to] swim in a typical spent nuclear fuel pool?

Answer: . . . You’d die pretty quickly, before reaching the water, from gunshot wounds.

– **XKCD: What If? #29**

COURTING DISASTER

Realistically, sabotaging a reactor is very hard to do – the people who design the plant and its security are well aware of the potential for disaster. Physical access is strictly controlled, which prevents most local crime, and permitted visitors are kept to areas where they can do no damage. Staff members are subject to psychological and drug testing, as well as a thoroughly ingrained safety culture. In poorer countries, reactors are military projects and guarded accordingly. Even physically attacking the containment building will achieve very little.

On a more cinematic level, these precautions fail. Disgruntled workers are suborned by the bad guys or decide to go out with a bang, the bosses insist that safety checks be skipped to keep profits up, protective structures have hidden weaknesses, and security guards fail to find concealed weapons.

A containment building, which usually consists of a steel pressure vessel surrounded by a concrete missile shield, normally has DR 7,000 or more, enough to withstand a passenger jet crashing into it or a thoroughgoing tornado; the core pressure vessel is about as strong. (The Fukushima containment buildings stood up to half-g accelerations from a magnitude-nine earthquake 100 miles away.) Although Western reactors have containment buildings, not all reactors outside the West are built with them. In particular, Soviet and Russian reactor designs tend not to use containment or to have only minimal structures. Where other countries such as Iran or India have borrowed Russian designs, they generally have added containment buildings.

The core vessel itself is a tough structure, but its fixtures and fittings can’t be made that strong. An attacker who can get in close can identify vulnerable points (a mere DR 500) with a roll against Mechanic (Fission Reactor) (p. 13), and he can potentially breach the core with antiarmor rockets or carefully-placed explosives.

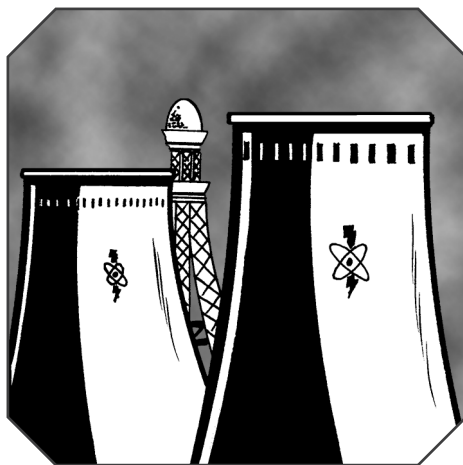
A fuel or waste cask for road or rail transport has DR 500-800 and is generally well-guarded. A typical 50-ton cask contains around 2.5 tons of waste (around 30 PBq of slow particulates; see p. 17); or the same amount of fuel (around 60 GBq of ultra-slow particulates, less immediately dangerous to the environment but more deadly if made into a weapon). The cask itself provides the shielding; anyone planning to steal the material should take this into account.

Fuel-enrichment and waste-processing facilities are just as secure as other nuclear sites, but they don’t have the reactor bubbling away in the background. They’re still likely to have plenty of noxious chemicals, though. Both may contain uranium hexafluoride (known in the industry as “hex”) – this is solid at standard temperatures and pressures, but reacts violently with water (including the water in human bodies), and should be treated in game terms as a strong acid (see p. B428). One of the byproducts of that reaction is hydrogen fluoride gas, which counts as a corrosive toxic atmosphere (see p. B429) with rolls at HT-6. Facilities like this are subject to the same sort of accident as any high-temperature industrial plant, but with bonus radioactive contamination.

CORE BREACH!

After a serious breach, radiation levels in the reactor building are 5,000-20,000 rads/hour and up. Basic safety equipment won't even *indicate* levels this high; the designers assume that once the level is more than around three or four rads/hour, personnel shouldn't be in there anyway. Plant workers can be fatally irradiated in less than a minute. Turbine halls, adjacent to the reactor building, receive up to 1,000 rads/hour, and even the control room may get three to five rads/hour.

Explosions often accompany a major release. Steam explosions caused by a runaway core may be as large as $6d \times 10$ multiplied by the square root of the reactor's capacity in MW. Hydrogen explosions from exposed fuel-rod cladding are usually smaller, as hydrogen in air ignites easily from random sparking and heat. However, if the explosions are delayed while hydrogen builds up in a containment building, they can potentially reach about the same size as a steam explosion.



Fire (up to $6d$ burning per second) is another hazard, especially if someone's been skimping on the plant construction and failed to use properly fire-resistant materials. The plant's own firefighters will have radiation gear and training, but outsiders called in to help with a big problem may not.

The main product of a meltdown is *corium*, a lava-like substance formed of fuel, moderator, and anything else that was too close at the time. This burns down to the foundations of the reactor building. In a sufficiently major accident, it could burn *through* the concrete and spread massive radioactivity through groundwater, potentially making large areas of land unusable for thousands of years – not to mention producing a massive cloud of radioactive steam. If someone gets in the way, that person receives $4d$ burning damage per second with radiation (see p. B105).

THREE SHAKES

Nuclear weapons are much harder to build than reactors, but they produce simpler effects much faster: thermal pulse, radiation, and blast. For the blast, take the square root of the yield in kilotons and multiply by 2,828 to find the multiplier to a basic $6d$ crushing explosive attack, rounding to the nearest 1,000 or so.

Linked to this is a burning explosive attack with the radiation and surge modifiers (representing the radiation and thermal pulse; see *Damage Modifiers*, pp. B104-105) equal to $2/3$ of the blast damage in size. Divide damage by $(2 \times \text{distance in yards from center of blast})$. In a detailed game, don't forget to apply *Flash and Blindness* (**GURPS High-Tech**, p. 182).

Example: A W87 warhead has a yield of 475 kilotons. The damage is $6d \times 62,000$ cr ex, with linked $6d \times 41,000$ burn sur.

A neutron bomb is designed with a different balance of radiation, blast, and thermal effects. A thin bomb casing allows more neutrons to escape rather than being converted to heat, so for the same nominal yield, the bomb produces less blast and heat but much more radiation. Use 80% of the square root of the yield (that is, multiply by 2,262) to calculate damage as above, but assess 10 rads per point of basic damage in the linked burning attack rather than the usual one rad.

A nuclear weapon detonated in or near the atmosphere also produces an *electromagnetic pulse* (EMP). Gamma rays strip electrons off atoms in the atmosphere, and those electrons spiral around Earth's magnetic field lines. As they collide with other particles, they release electromagnetic energy. This induces huge currents in conductive materials, which can damage or destroy electronics. In atmosphere, this is unlikely

to produce a significant effect outside the main area of blast damage (ignore EMP effects where radiation damage is less than $6d$), but a 1.44-megaton test 250 miles above the Pacific in 1962 damaged equipment 900 miles away in Hawaii. It is estimated that a 10-megaton detonation 200 miles above the center of the United States would affect the entire country.

Treat EMP as an Affliction that only affects electronics and those who have the Electrical disadvantage (p. B134). This effect is distinct from the surge modifier on the explosion's burning damage! Every vulnerable target in the radius of the EMP suffers a HT-8(2) affliction attack. A failed resistance roll means that item is knocked out of action until repaired. Affected solid-state technology is likely permanently damaged; all repair rolls are at -10. Repairs on other devices are at only -4. Machinery can be designed with surge protectors – it will still fail when the EMP hits, but protection can give as much as +8 to the post-EMP repair roll.

A variety of TL7-8 military hardware is shielded entirely against EMP. Fiber-optic transmission lines are also immune. Other equipment can be protected by surrounding it with metal that is in turn grounded, though any equipment which needs to receive electromagnetic radiation to work (radios, radars, etc.) will not function while shielded. For characters, Resistant (EMP) can represent shielding; EMP is a "Rare" effect.

Cinematic EMP causes all electronic equipment within miles to fail catastrophically: planes fall out of the sky, cars stop, and cities go dark, but hardware that was shut off at the time of the pulse can readily be made working. In the ultra-cinematic version, all electronic equipment is irreparably destroyed and civilization ends.

EFFECTS OF RADIATION

Exposure to excessive amounts of radiation causes harm to the body, as discussed under *Radiation*, pp. B435-436. What happens and when depends on the size of the radiation dose.

RADIATION SICKNESS

These new options add realism to the standard **GURPS** radiation rules (pp. B435-436) for those who are repeatedly exposed to small doses.

To track radiation damage, use two measures: Current Radiation Load and Lifetime Dose. Whenever someone is exposed to radiation, add the number of rads to *both* figures.

(See the *Typical Radiation Dose Table*, p. 7, for examples.) Once per day, subtract 10 rads from Current Radiation Load. TL7 and later radiation treatment subtracts a further 10 rads per day, and Regeneration that affects radiation also gives benefits. If that number is still above zero, make an HT roll on the *Radiation Effects Table* (p. B436), and apply any effects. Ignore mentions of Terminally Ill. Make HT rolls only on days the person is exposed to a new dose, and apply only the worst effect of all those rolled; the victim recovers from it as listed.

Lifetime Dose simply increases. It has no acute effects, but it increases the likelihood of cancers later in life. This is something for the GM to work out with the player rather than allocate randomly, but as a rough guide, a human character would normally have to fail a HT+2 roll to get a potentially lethal cancer during his lifetime; each 200 rads of Lifetime Dose would give -1 to that roll.

RADIATION THRESHOLD POINTS

The following alternative rules vastly simplify radiation absorption, and replace the existing rules on pp. B435-436 and the Radiation Tolerance advantage. The effects of radiation, which primarily sicken the victim, no longer depend on an HT roll – and (by default) it's always possible to recover from it fully. The GM should inform the players whether the campaign will use RP or the more complex, realistic approach in the *Basic Set*.

Everyone has a new secondary characteristic, *Radiation Threshold Points* (RP), the base value of which is equal to $(ST + HT)/2$, rounded down. It may be raised to a maximum of $ST + HT$, or lowered to a minimum of $(ST + HT)/4$, for ± 1 point/level.

The RP score is used to track radiation absorption. Losing 1 RP is *roughly* the equivalent of accumulating 10 rads. As your RP drops, you suffer from the following effects.

Less than 1/3 of your RP left – You are queasy and slightly dizzy: -1 to all attribute and skill rolls. The only exceptions are passive resistance rolls (e.g., a HT roll to avoid contagion).

0 RP – You are sick to your stomach: -2 to all attribute and skill rolls, and -1 to all active defenses. If you lose further RP, each point you lose *also* costs you 1 FP. Remember that once your FP goes below 0, you begin losing HP as well; if you cannot safely rest and recover, this will eventually kill you.

-1xRP – You are reeling and woozy: -4 to all attribute and skill rolls, and -2 to all active defenses. In addition, make an unpenalized HT roll every second or fall unconscious (recovery depends on your current HP; see p. B423). *Exception:* You do not have to make this roll if you are walking no faster than Move 1 and do not attempt any physical action or defense roll; in combat, this requires a Do Nothing maneuver each turn.

-5xRP – If you weren't already unconscious from FP loss, you pass out now and will not wake up unless you can heal your RP above this threshold. Make an unpenalized HT roll. On a failure, you are treated as mortally wounded (p. B423); on a critical failure, you die! On a success or critical success, roll again every hour until you fail.

-10xRP – It's amazing that you've survived this long. Sadly, this is no longer the case. You are dead.

You naturally recover 1 RP every 24 hours, whether you are resting or not. Very Rapid Healing doubles this rate, to 1 RP every 12 hours. Regeneration which affects radiation heals RP at the same rate at which it would heal HP. This assumes your RP score is less than 20; multiply your healing rate by 2 for RP 20-29, by 3 for RP 30-39, by 4 for RP 40-49, and so on.

RADIATION DAMAGE TO EXOTIC PEOPLE

Other effects may be relevant even to exotic people who have no hair to fall out or blood to decay. (Normal humans will usually be dead well before these become important, but if they somehow survive, they also are subject to these additional problems.)

Radiation Tolerance reduces all of these effects. For non-neutron radiation embrittlement (see below), Immunity allows a roll at HT+15 rather than the normal HT.

Something with the Electrical disadvantage must make an HT+4 roll for each 100 rads it is exposed to, at -1 for each 100 rads accumulated dose; Resistant (Radiation) helps towards this. On a failure, the gear shuts down until it is repaired. On a critical failure, it is destroyed, and any data stored on it is lost. "Hardened" electronics typically have a Protection Factor of around 1,000.

Any material being taking a truly intense radiation dose (for example, if acting as part of a reactor pressure vessel) may be subject to radiation-induced *embrittlement* as its very structure is damaged. For every billion rads accumulated dose, make an HT roll, -1 per full billion rads, or permanently lose a level of HT. If the dose comes primarily from neutron radiation, don't even make the roll – just lose the HT. If the being can survive enough heat for the molecular structure of its materials to rebuild (500°F-1400°F for various steels), this HT loss can be removed by annealing for several hours.

OTHER RADIATION EFFECTS

As a guideline, many people can survive a dose up to about 500 rads in the short term even without medical care, or up to 800 or so if care is provided; anything more than that is certainly fatal. Those numbers drop by around half in a population that's already unhealthy. In the longer term, even doses well below the level needed to cause noticeable acute radiation sickness seem to lead to increased levels of cancer (especially leukemia) and birth defects in offspring.

Even purely psychological effects on those who think they *may* have been exposed to dangerous radiation doses can apparently shorten their lives by around five years. At the very least, a credible threat of radiation exposure should call for Fright Checks (see *Radioactive Terror*, p. 24) – and people without relevant skills will find almost any threat credible.

Cinematic PCs are debilitated in the same way as others, but usually won't die of radiation exposure even when they miss their HT rolls; their FP and HP won't go to zero just from radiation. Instead, they can stagger

around at -5 to all rolls until they get treatment. Alternatively, use Radiation Threshold Points (p. 16).

Some settings have a hazard which acts a bit like radiation, but doesn't have the normal ill effects. Instead, someone who picks up enough of this special radiation changes in some way, perhaps becoming a zombie (see *GURPS Zombies*, particularly *Radiation Ghoul*, p. 91) or developing "mutant powers" (see *Superhero Origin Stories*, pp. 13-14). Use the *Radiation Effects Table* (p. B436) to determine the modifier to the resistance roll based on cumulative dose; a failed HT (or perhaps Will) roll means that the effect takes place.

If the effect is a positive one, reverse the modifier, and the change takes place following a *success* on the roll.

In the map of nearly every country of the world three or four more red circles, a score of miles in diameter, mark the position of the dying atomic bombs, and the death areas that men have been forced to abandon around them.

– H.G. Wells, *The World Set Free*

CHAOS

Once radioactive material has got out, it spreads. *GURPS High-Tech*, pp. 195-196, gives a model for use with nuclear weapons: The primary contaminated zone is 800 yards long by 200 yards wide for a 0.1kt device used in a ground burst, each dimension doubled for each tenfold increase in yield. Within this area, assess 100 rads/hour if passing through a few hours after detonation, 10 rads/hour two days later, and one rad/hour two weeks later. This shape is the result of wind carrying contaminants away from the blast site; if there is no wind at all, it will be a circle 200 yards wide, with four times the dose rate. An air burst disperses the fallout much more widely, and doesn't produce a high-radiation zone.

The fallout released from a reactor is very different in composition from what's dispersed by a ground-burst nuclear weapon (which consists of the pulverized remains of the fissile material and the target area). For simplicity, three main classes of substances can come from nuclear meltdowns, radiation leaks, and other nonbomb sources: *slow particulates* such as cesium-137 and strontium-90, which are relatively inactive but persist for a long time; *fast particulates* such as iodine-131, which is highly active and becomes concentrated in particular organs of the body; and *fast gases* such as xenon-133. (There are also *ultra-slow particulates*, such as uranium-235 itself, but these do not generally form a significant proportion of a radioactive release; even if they get loose, they stay in the immediate area of the core.) The GM will need to select the amount of each component in the release, using historical examples (pp. 18-19) or the demands of the plot as a guideline.

For each class, divide the leak's size in PBq by 500 to approximate the dose rate in rads/hour. This spreads at about 15 mph into the immediate footprint, which is very roughly an ellipse 20 miles long and five miles wide. Scale the dose

rate up or down with the size of the release, but the area stays about the same. This footprint is subject to distortion by wind (which can increase the spread rate to as much as 40 mph) and weather (rain will make it smaller but more intense) and may be an irregular shape, or even circular in the rare case of no wind at all. In extreme weather conditions such as a hurricane or tornado, the main footprint may not form at all – all the contaminants are carried away and dispersed across a much wider area, at a concentration too low to be dangerous.

The *rate* at which the types of contaminant decay varies substantially:

- *Slow particulate* contamination takes many forms. Some of it will be dust that is inhaled or sticks to skin, some of it will dissolve in water, and some of it will simply lie around emitting gamma rays. Halve the dose rate each 30 years. (*Ultra-slow particulates* continue at the same dose rate indefinitely, getting into timescales of thousands or millions of years.)
- *Fast particulates* behave roughly like the slow ones, but the mammalian body concentrates them into particular areas (in the case of iodine-131, the thyroid and milk glands). Halve the dose rate each eight days.
- *Fast gases* are heavier than air and spread quickly at ground level before mixing with air and dispersing if there's any more wind than a dead calm. Fast gases are inhaled by unprotected victims, doing significant damage, but are largely harmless to those with their own air supplies. Halve the dose rate each five days; if there's significant wind, the dose disappears completely after the first day.

Fast and slow particulates become lodged in the bodies of those who spend at least an hour inhaling the particulates. The victims take half the dose rate on an ongoing basis for 30 days or until they receive chelating drugs.

Example: The Chernobyl event released 85 PBq of slow particulates, 1,760 PBq of fast particulates, and 5,200 PBq of fast gases into the footprint, which included the town of Pripyat. At the time of release, the dose rate was roughly $0.17 + 3.52 + 10.4 = 14$ rads/hour (though people with closed air supplies can ignore the gases and take only 3.7 rads/hour). Assuming no wind, 40 days later, the fast particulate dose was halved five times, and the fast gas dose eight times; the dose rate became $0.17 + 0.11 + 0.04 = 0.32$ rads/hour. An unprotected person on day one, who inhaled particulates and then left the area, took $(0.17 + 3.52)/2 = 1.8$ rads/hour for the next 30 days or until he received treatment.

Outside the footprint, the pattern of contamination becomes even more irregular and dependent on wind patterns. After Chernobyl, contamination spread much more strongly into Finland and Sweden to the northwest, and into northern Italy and Yugoslavia to the southwest, than into Germany (which lies between the two). Very roughly, quarter the dose for each doubling of the distance from the center of the release, but there will be “hot” and “cold” spots.

Most emergency responders are not trained to deal with radiation incidents, and the initial reaction is likely to be disorganized. See Chapter 4 for adventure suggestions based on the type of world and the importance of the disaster to the plot.

AFTERMATH

So far, the world has only one example of a major radiation release into a thriving ecosystem. The pine forest downwind of Chernobyl died and turned a ginger-brown color; it is known today as the “Red Forest.” Animals moved into the exclusion zone as humans left it, and while the mutation rate is certainly higher than usual, most of the mutations are less viable than normal creatures and have died off rather than passing on their modified genes. The wildlife population was much more badly affected by trying to coexist with humans than it is now by the radiation.

Most mammals react to radiation in roughly the same way as humans, but other species have highly variable tolerances. Birds have nested in the remains of the reactor building, and while some have stunted tail-feathers, most look quite normal. Decay organisms seem to be very bad at coping with radiation, so dead animals and plants lie where they have fallen, rotting only very slowly. Some fungi have mutated to produce melanin and feed off residual radiation in the reactor core. Some bacteria, such as *deinococcus radiodurans*, can withstand hundreds of thousands of rads.

OTHER SOURCES OF RADIATION

This supplement deals mainly with power-reactor accidents, since they have provided the majority of radioactive contamination to date. Other sources occur on a smaller scale. For example, in 2000, an old cobalt-60 medical radiation source of around 15.7 TBq was stored in an unsecured location in Bangkok, then stolen and sold to scrap dealers. The junkyard workers dismantled the casing and left the contents lying around for several days, taking doses up to 600 rads. Ten of them became seriously ill, and three died. In 2013, a truck carrying a disused 111 TBq cobalt-60 medical source for disposal was hijacked near Mexico City. The truck was recovered, and later the source itself, but the thieves had cut away the shielding, almost certainly taking a lethal dose in the process.

Accidents at medical or research isotope production plants and reactors can readily lead to minor radioactive releases, in part because a smaller facility can’t afford the extremes of safety and security available at power reactors.

The long-term health of an area depends on the type and amount of contamination. Land tainted with massive doses of slow particulates may be unusable for decades or centuries; ultra-slow particulates are typically heavy elements that are not absorbed as readily into the environment, and the atomic detonation site at Hiroshima (exposed to around 90 TBq) could be safely visited within a few months of the bombing.

A sufficiently energetic release of particulates that reach the upper atmosphere, probably the result of large-scale nuclear bombing rather than reactor meltdowns, is forecast to cause a “nuclear winter.” This phenomenon is an overall reduction in temperatures by 20-40°F across the world as sunlight is reflected away rather than reaching the surface. The ramifications of this include mass starvation as crops fail, waves of survivors move toward the equator, and the ozone layer further depletes.

THE LESSONS OF HISTORY

In order to give a feel for the scale of nuclear accidents, here are five examples from the real world.

WINDSCALE

In 1957, this air-cooled graphite-moderated reactor, used to produce tritium for the British H-bomb program,

caught fire thanks to a combination of lack of knowledge and instrumentation failures. Total radiation release was around 13 PBq, of which 12 PBq was fast gases, 740 TBq fast particulates, and 22 TBq slow particulates. There were no deaths or excessive radiation doses. The release of iodine-131 led to memorable television images of local milk being poured into ditches.

K-19

The first Soviet nuclear-powered ballistic missile submarines were the Hotel class (Project 658), driven by a pair of 70MW pressurized water reactors. In 1961, the first of these boats was on its maiden voyage when a coolant leak developed. A SCRAM was implemented, shutting down the reactors, but decay heat brought core temperatures even higher and a meltdown was threatened. The ship's engineers jury-rigged an emergency cooling system; typical radiation doses were around 800-1,000 rads, and they all died within three weeks. The rest of the crew survived, and the reactors were replaced and dumped at sea. The boat was known informally as "Hiroshima" for the rest of its service career.

THREE MILE ISLAND

TMI-2 was a pressurized water reactor. In 1979, secondary cooling pumps failed. The reactor overheated and automatically underwent a SCRAM, but decay heat increased the core temperature and cooling was not available to remove it. An emergency pressure-relief valve stuck open, a collection tank ruptured, and some 32,000 gallons of radioactive water and steam were lost to the environment. The upper part of the core, now completely uncooled, melted down, contributing fission fuel and products to the steam release. The vast majority of the contaminated material was stopped within the plant, though outside the containment boundary. No verifiable environmental or health effects occurred, and nobody died or was exposed to an excessive radiation dose. However, it's believed that around 100-500 PBq of fast gases and 500-600 GBq of fast particulates were released. It didn't help that this happened less than two weeks after the release of the film *The China Syndrome*.

CHERNOBYL

In 1986, a test of new emergency procedures on #4 reactor at the V.I. Lenin power plant in the Ukrainian SSR went very wrong. The boiling water reactor experienced an uncontrolled power surge, and its coolant water exploded as steam, destroying the reactor core and its external casing and spraying pieces of fuel, components, and structural materials into the outside world. When the

graphite moderator ignited, the fire and smoke spread debris even further.

Total radioactive release was around 15 EBq from approximately six tons of fragmented fuel, around 4% of the plant's total fuel load; 5,200 PBq was fast gases, while slow particulates (85 PBq) and fast particulates (1,760 PBq) were the major biological concerns. (The remainder was ultra-slow particulates which didn't spread far.) The exclusion zone, still closed to unauthorized personnel 30 years later, covers 1,000 square miles around the plant; it's contaminated largely with strontium and cesium. The generally accepted number for fatalities as a direct result of the disaster is 41 people, but that toll includes four who died in a helicopter crash. Around 4,000 more thyroid cancers than usual were found in people from the affected area, although most of those were treatable.

FUKUSHIMA

The Fukushima Daiichi nuclear power plant was built to stand up to earthquakes and tsunamis of a scale expected to be seen only once per century. In March 2011, it was hit by a disaster of a scale expected only once per 10 centuries. Three of the six boiling water reactors on the site were active, and they shut down automatically when the earthquake struck, turning off all power generation. Emergency diesel generators were brought on-line, but switching rooms flooded when the tsunami hit the site 50 minutes later, and the only remaining power source was backup batteries. Power was lost to the coolant circulating pumps, and the three reactors that had just been shut down started to overheat. (Seawater was considered for emergency cooling, but not used when it might still have helped because this would have permanently ruined the reactors.) All three live reactors melted down. In two of them, reactions between boiling water and zirconium-alloy cladding on the fuel rods produced hydrogen gas, which exploded in air, spreading the fallout further.

Around 15 EBq of fast gases were released (most of them dispersed harmlessly over the sea), as well as 15 PBq of slow particulates and 500 PBq of fast particulates. Some 18,000 people died from the earthquake and tsunami or during the evacuation after the disaster, with 2,000 still unaccounted for. Officially, nobody died of radiation, though two workers were hospitalized.

*This message is a warning about danger . . .
The danger is still present, in your time, as it was in ours . . .
The danger is unleashed only if you substantially disturb
this place physically. This place is best shunned and left
uninhabited.*

*— proposed long-term message at
Yucca Mountain Nuclear Waste Repository*

CHAPTER THREE

RADIATION GEAR

Specialized equipment for dealing with radiation hazards is often adapted from other hazmat equipment; some of it had to be invented for the job. All these items may be upgraded at higher cost; see *Equipment Modifiers* (p. B345).

Air Tank (TL6). A small tank of compressed air lasts 12 minutes, weighs 15 lbs., and costs \$200. A medium tank lasts 22 minutes, weighs 25 lbs., and costs \$400. A large tank lasts 45 minutes, weighs 35 lbs., and costs \$600. Double duration at TL7; double again at TL8. Subtract one minute per FP expended and per Fright Check failed. LC4.

Contamination Monitor (TL6-8). Typically a low-sensitivity Geiger counter, this scans personnel leaving a nuclear facility as they walk past. \$400, 1 lb., external power. LC4.

Decontamination Shower (TL6). This one-person shower catches contaminants and pumps them into drums. Set up at the edge of a hazmat safe zone, everybody coming out of the contaminated area must move through it. Likely to be fitted aboard larger vehicles, such as warships. \$600, 150 lbs. LC3.

*Fallout can kill, though
you cannot see it, feel it or
smell it. There is danger
outside, so don't go outside.
Stay in your fallout room
until you are told it is safe
to come out.*

– HMSO,
Protect and Survive

Decontamination Sprayer (TL6). Has enough decontaminant for 10 people or two vehicles. \$500, 35 lbs. Halve weight at TL8. LC3.

Film Badge (TL6). This is simply a piece of photographic film in an opaque holder; it's worn continuously and fogged by exposure to radiation. The dose is only apparent when it's developed. \$2, neg. LC4.

Filter Respirator (TL6). A simple absorbent pad which covers nose and mouth; it provides Filter Lungs, but does nothing against toxic gases. \$6, neg. LC4.

Geiger Counter (TL6). Detects alpha and beta radiation well, gamma poorly, and neutrons only with specialized variants. This will give the user a general idea of the level of hazard, but no details. \$800, 4 lbs., 4XS/4 hrs. At TL8, also has a digital display. \$400, 0.5 lb., XS/10 hrs. LC4.

Potassium Iodide (TL6). Someone who might get exposed to iodine-131 can dose himself with clean iodine beforehand or immediately afterward; that way the thyroid gland doesn't take up as much of the radioiodine. It offers no protection against any other radiological hazard. \$0.20 per tablet (one day's dose), neg. LC4.

Radioactive Poison (TL6). A highly active substance like radium-226, americium-241, or polonium-210 can be an effective poison. A few micrograms will produce an ongoing dose of around 0.5 rads/hour, and chelating drugs won't help once it's spread through the body. Death usually follows in a few weeks to months. This sort of substance is never available on the open market. \$10,000,000 and up per dose. LC0.

Biohazard Suit (TL7). A bulky, hermetically sealed suit worn for protection from chemical spills and plagues. It cannot pass for clothing. It's worn with an air mask or an air-tank system, which fits completely under the suit. It's incredibly hot – triple FP losses while suited up. At TL8, advanced versions (×2 cost) have a special lining that effectively blocks low-level radiation, providing a PF of 2.5. It uses the NBC Suit skill. DR 1 against burning or corrosion damage, \$500, 8 lbs. LC4.

Chelating Agents (TL7). This cocktail of drugs removes radioactive matter from the body, halving any ongoing dose from particulate contamination (see *Chaos*, pp. 17-18) after three days and reducing it to zero after a week. At TL8, it removes all particulate dose in 12 hours. The cocktail also eliminates metals such as antimony, arsenic, and lead, giving +TL/2 to HT rolls against these kinds of poisoning. However, the body becomes dehydrated: Increased Consumption (Water Only, -50%) for 12 hours. \$500 per daily treatment. LC3.

Gamma Spectrometer (TL7). Detects gamma radiation, the principal hazard of almost all radioactive contamination. This is a handheld version; larger models are used at ports and freight terminals to detect radioactive cargo. As a spectrometer, it allows the user to work out in detail what radioactive substances are present. \$8,000, 10 lbs., 4XM/3 hrs. or external power. At TL8, \$4,000, 0.25 lb., 2XS/8 hrs. or external power, and also acts as a thermal neutron detector (p. 21). LC4.

NBC Suit (TL7). A *disposable* quilted suit with a charcoal lining that protects against radioactive fallout and poisonous gases, though not against direct radiation. It quickly loses its seal in a wet environment, and it must be stored in an airtight container before use. After 72 hours at most, it's no longer reliable protection. It uses the NBC Suit skill. DR 1 against burning or corrosion damage. \$150, 3.5 lbs. LC4.

Portable Isolation Dome (TL7). A light plastic dome about 3' across, with an airlock and glove inserts, for handling small hazards. DR 3. \$500, 5 lbs. LC4.

Quarantine Tent (TL7). A tent sealed against chemical and biological threats, with an airlock and a filter system. It keeps out fallout, but not radiation. Has enough space for a couple of examination tables and ancillary equipment. DR 1. \$2,000, 50 lbs., external power. LC3.

Radiation Badge (TL7). This ID badge has a color strip indicator that shows the total dosage to which it has been exposed. \$5, neg. LC4.

Stretcher Isolator (TL7). A sealed stretcher on wheels, with glove inserts, biomedical sensors for +1 (quality) to Diagnosis, and an intercom. Requires air tanks. \$5,000, 500 lbs., L/10 hrs. LC3.

Thermal Neutron Detector (TL7). Detects slow (thermal) neutrons. This is a handheld version; larger models are used at ports and freight terminals to detect radioactive cargo. \$9,000, 12 lbs., 4xM/3 hrs. or external power. At TL8, \$1,500, 0.5 lb., 2xXS/8 hrs. or external power. LC4.

Advanced Anti-Radiation Drugs (TL8). Including developments such as Ex-Rad and Entolimod (CBLB502), these new drugs encourage the body's own defenses to fight against radiation damage by scavenging free radicals, inhibiting cell death, and inducing DNA repair. A month of treatments at 12-hour intervals will halve Lifetime Dose (p. 16) and reduce Current Radiation Load (p. 16) by the same amount. \$120,000 for a course of treatment. LC3.

Casualty Bag (TL8). A sealed bag with a battery-powered air filter, for short-term hazmat evacuations. \$100, 5 lbs., M/2 hrs. LC4.

EOD Robot (TL8). This is a lightweight tracked bomb-disposal robot with option packages for hazardous materials, similar to the Foster-Miller/QinetiQ HAZMAT TALON. It is remotely controlled via radio or fiber-optic cable, and it transmits images in color or with Infravision or Night Vision 9 to an operator half a mile away. It has a single ST 3 claw with Bad Grip 3, and it can be fitted with any of the sensor equipment listed here. It has the Machine meta-trait plus the Sealed advantage and Electrical disadvantage. Heavier and stronger versions are available. Move 2, SM -1, HP 10. \$80,000, 120 lbs., 2xL/4.5 hr. LC2.

Fast Neutron Spectrometer (TL8). This device not only detects fast neutrons but also classifies them by energy, giving detailed information about the presence of transuranic elements and fission or fusion processes. \$5,000, 10 lbs., external power. LC3.

Imaging Gamma Spectrometer (TL8). This bulky and expensive detector needs cryogenic cooling, but it counts as "best equipment possible" for +4 to detection and analysis. As well as acting as a gamma spectrometer, this device lets the user see exactly where radiation is coming from, rather than needing a probe moved slowly through a suspect area. Field models, which take an hour to cool to operating temperature, are \$20,000, 12 lbs., 2xM/4 hr. LC3.

Personal Dosimeter (TL8). Industrial or military versions are the size of a pager, but the electronics can be miniaturized to fit inside a wristwatch. These will detect alpha, beta, and gamma radiation, give a continuous readout of total dose and dose rate, and can sound an alarm if either exceeds set thresholds. \$120, 0.5 lb., 2xXS/yr. LC4.

Portal Monitor (TL8). A sequence of radiation monitors (gamma and neutron detectors) on either side of a roadway. Vehicles pass through slowly, and the monitor sounds an alarm if the radiation level rises too high, after which the vehicle can be searched with handheld detectors. \$55,000, 300 lbs., external power. LC3.

Radiation Blanket (TL8). A 4'x6' piece of flexible ballistic armor, used to contain an explosion if a bomb can't be removed. It provides DR 25 and PF 3 to anything it covers. \$2,000, 90 lbs. LC4.

Radiation Suit (TL8). A heavy, metal-lined full-body coverall, used when working around radioactive substances, it provides PF 3 against all radiation. Worn with an air tank or piped air, but still hot; double FP losses while in use. It is reusable if it does not come into direct contact with radioactive solids (including dust) or liquids. It uses the NBC Suit skill. DR 2. \$1,600, 9 lbs. LC4.

FUTURE TECHNOLOGY

Advancing medical technologies such as cloned or replacement organs could heal radiation damage by simply replacing the damaged parts of the body. Assume that someone's Current Radiation Load and Lifetime Dose are reduced in proportion to the amount of body mass that is replaced. An intense localized dose, like a hit to the arm from a gamma-ray laser, may be completely cured if a transplant is provided quickly enough.

Superscience developments, such as force fields and nuclear dampers, may render radiation obsolete as a danger. People living in a world where nuclear hazards are cleaned up as routinely as litter in the street may not even recognize the symptoms of radiation sickness, any more than most modern humans would recognize bubonic plague.

For TL10 equipment, check out HEX suits (*GURPS Ultra-Tech*, p. 184) and radscanners (*Ultra-Tech*, p. 63).

Antirad (TL9): One dose halves the effective amount of rads from a new exposure; two doses will halve exposure again, and so on. Antirad is preventative; it does not heal radiation damage. It comes as an injection or pill for \$150 per dose.

Blast Foam (TL9): Ballistic foam forms a non-conductive polymer-ceramic blanket. Designed to be sprayed over a bomb, it hardens in three seconds and forms a thick layer that can absorb explosions, contain fragments, and sterilize chemical, biological, and radiological agents. Each second of spray can coat a square yard, providing ablative DR 40 against crushing and burning damage, and ablative DR 20 against other types of damage. If the foam contains the blast, it is also treated as sealed with radiation PF 5. Each square yard of foam weighs 10 lbs. Anyone completely coated with the foam may suffocate (p. B436); he can inflict his normal thrusting damage on the foam to try to escape. A canister of foam that can cover three square yards is \$100, 30 lbs. LC3.

Wristwatch Rad Counter (TL9): This measures and displays the amount of radiation that the user is exposed to, and can be programmed to set off an alarm if dosage exceeds a designated level. The same unit can present information on an HUD, or be built into a helmet visor. \$100, neg., A/6 mo.

CHAPTER FOUR

CAMPAIGNS AND ADVENTURES

A core theme of radiation accidents is that the severity level isn't obvious. You can see a lava flow or a swarm of giant wasps or damage from an earthquake, but you need instruments to

detect and track radiation. (*Nuclear* accidents are easier to spot – just listen for the boom, and look for the steam plume or mushroom cloud.)

SETTING

Stories about accidents with nuclear power are most easily set on modern or recent historical Earth, for which plenty of concrete examples are available, or on fictional worlds with a comparable tech level (TL7-8). Before the 1950s, nuclear power didn't exist; in the future, we can hope it'll be a bit more reliable. But the concepts of radioactive contamination can be used in almost any setting. For a more cinematic approach to radiation, *GURPS Atomic Horror* has useful advice and a decent filmography.

MODERN EARTH

All countries with nuclear power programs have made some preparation for mishaps, though level of preparedness and quality of equipment varies widely.

In the United States, power plants have emergency-response teams, plant personnel, and outsiders who continue with their normal jobs but are trained for specific roles in the case of an incident (including searching for radioactive material, checking the population for exposure, press management, and so on). If criminal activity is suspected, the FBI becomes involved at once. The Nuclear Emergency Support Team (NEST) provides technical expertise to the FBI and other federal law enforcement agencies, and is particularly trained in searching for and disarming terrorist devices with a radioactive component. General regulation and inspection is handled by the Nuclear Regulatory Commission, which is often regarded as too beholden to the industries it regulates.

In Russia, Rosatom State Atomic Energy Corporation is in charge of all civil nuclear activity, and it even runs some nuclear weapons factories. Following Chernobyl, Russia's cleanup crews have developed a reputation for practical expertise, and Rosatom is prepared to deal with countries that the West won't touch.

In Japan, all reactors were hastily shut down in 2011. The Nuclear and Industrial Safety Agency and Nuclear Safety Commission were replaced in 2012 by a new Nuclear

Regulation Authority, the main job of which has been to write new safety standards for future operations and begin the reactivation of a few plants. Fuel reprocessing has continued throughout.

In the United Kingdom, the UK Atomic Energy Authority was once in charge of all nuclear development, civil and military. It has gradually seen its functions reduced, with various offshoots such as British Nuclear Fuels Ltd and British Energy coming and going, until the present situation with Électricité de France running the remaining power reactors, Urenco producing nuclear fuel in several countries, and all other British activity being based on decommissioning older stations. The Civil Nuclear Constabulary (p. 27) deals with nuclear-related criminal activity.

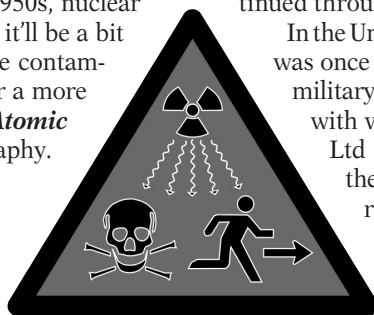
The Atomic Energy Organization of Iran runs the Iranian power program. The Revolutionary Guards would oversee any nuclear weapon development, though clearly the two groups would cooperate.

In France, all nuclear plants are operated by Électricité de France (85% government-owned), with construction and services done by the Areva group (79% government-owned). The Nuclear Safety Authority (ASN) handles power-plant regulation and inspections, while the Atomic Energy and Alternative Energies Commission (CEA) conducts research.

In Germany, four companies operate nuclear plants, under the supervision of the government-owned Reactor Safety Authority (GRS), which also conducts research.

In India, the government-owned Nuclear Power Corporation of India (NPCIL) operates domestic and foreign-built plants, shortly to be joined by the government-owned BHAVINI. Regulation and inspection are conducted by the Indian Atomic Energy Commission.

In Canada, power reactors are run by government-owned corporations such as Ontario Power Generation and NB Power. Safety is overseen by the Canadian Nuclear Safety Commission.



On a transnational level, the International Atomic Energy Agency is an intergovernmental forum for the promotion of peaceful uses of atomic power, as well as the implementation of safeguards against the development of nuclear weapons by countries that don't already have them. On the military side, its inspectors examine civil nuclear sites to make sure they aren't being used for weapons development, and report any problems to the United Nations. This can include remote and concealed radiation monitors and photo analysis to locate sites which officially don't exist at all. On the civilian side, it advises on nuclear safety; after its perceived inaction following major radiation releases, there have been proposals to enlarge the inspectorate with civil nuclear technicians who would go into friendly countries to advise on safety and cleanup.

In the event of a major radiation release, the host country will certainly assign military cleanup teams as well. They may be trained to deal with fallout from nuclear weapons, but basic decontamination procedures are much the same.

HISTORICAL EARTH

In the early days of nuclear research during the Manhattan Project, safety standards were a lot lower; several scientists and other workers died from accidental criticalities. Before Three Mile Island, there was a general sense that nuclear power was safe and harmless, so shortcuts could be taken. After all, it hadn't gone wrong before. One of the major problems at Three Mile Island was that a sensor measured whether the solenoid to close the valve had activated (which it had), rather than whether the valve had actually closed (which it hadn't); it was slightly cheaper to build it that way.

In earlier times, no *technical* reason exists why a simple boiling water reactor couldn't be built by any society that can produce a steam engine, has discovered radioactivity (which happened on Earth in 1896), and has developed the ability to mine (open-pit will do at first), purify, and mildly enrich (by thermal diffusion) uranium for fuel. The engine could be either static for pumping and industrial power or mobile for haulage – a nuclear reactor is just another way of heating water, after all, and can be plumbed into a conventional set of steam cylinders and pistons, even if it can't be run as hot and efficiently as later systems. If someone tries this in the early days of low-pressure steam engines, it will be monstrously dangerous. However, with sufficiently cunning engineering, a *reasonably* safe design should be possible by the early 1800s (mid- to late TL5). Workers with giant brass hand-wheels wouldn't react to a problem as quickly as a computerized control system, and some of the failures would result in radioactive steam clouds.

THE FUTURE

As technology advances, we can expect to see better drug and nanotech treatments to control and even repair radiation damage. Advances in computers and control systems could make it possible to instrument and inspect more and more of what's going on in a reactor. This will produce too much data too quickly to be tracked directly by human controllers, but sufficiently expert software

could spot problems and correct them well before they get a chance to become serious . . .

. . . As long as the software isn't sabotaged.

For a team that's set up to deal with this sort of problem and other disasters, see *Transhuman Space: Wings of the Rising Sun*.

In Space

All current reactor designs, and especially passively safe ones, rely on gravity to produce convection and a natural flow of coolant upward through the reactor core, which is then supplemented with pumps. Nuclear-powered spacecraft will have to modify these designs or put them in parts of the ship supplied with spin or artificial gravity. (Relying on gravity to keep the reactor running, and on the reactor to supply power for the artificial gravity, seems like a recipe for disaster.) If pumping fails, noncirculating coolant will heat up faster than in an earthbound reactor, giving even less time to deal with the problem. When something goes wrong, there's nowhere to run. Dumping the reactor core into space may stop the crew dying of radiation sickness, but now they're stuck in space without power.

OUR FRIEND, THE ATOM

During the 1950s and part of the 1960s, it was assumed that atomic power would soon be everywhere. Four cargo ships were tested with nuclear propulsion, and the Soviets were known for their nuclear icebreaker fleet. An expected need for long-range bombers saw American and Soviet experiments in nuclear propulsion for aircraft, starting with the NB-36H, a test bed to see if a reactor could be safely carried aboard an aircraft. (It could, but the shielding was extremely heavy.) The most extreme proposal was undoubtedly Project PLUTO, a Mach 3 open-cycle nuclear ramjet-powered cruise missile which would have left a trail of fallout and devastating shockwaves in addition to the nuclear warheads it would be ejecting en route. Some basic hardware was tested, but none of these projects ever got as far as formal development.

Less effort seems to have gone into nuclear-powered railway locomotives, though Dr. Lyle Borst's team at the University of Utah came up with the X-12 design in 1954; the demands of small size led to a liquid core, made from weapons-grade uranium dissolved in sulfuric acid. There is no evidence of any attempt to build this. In 2011, the Russian nuclear agency Rosatom claimed that it was building a locomotive around a fast breeder reactor, mostly to make a power plant that could self-deploy to remote areas.

Companies even created mock-ups of nuclear-powered cars, notably the Ford Nucleon (1958) and the Studebaker-Packard Astral (1957). None of them ever got as far as a prototype. Building small reactors turns out to be *difficult*, quite apart from concerns of public acceptability.

In a TL(7+1) world of truly mad science, routine automobile accidents may cause minor reactor meltdowns and spray a few PBq of weapons-grade uranium across the road, as well as highly radioactive acid or molten sodium. Recruitment for the traffic police would be challenging.

Smaller TL8 spacecraft use RTGs or other nuclear batteries (see *Nuclear Batteries*, p. 5), which do not rely on gravity. They're not designed to be serviced, but they're also not designed to be able to go wrong, short of catastrophic damage.

Some theoretical reactor designs for spacecraft propulsion use liquid- or gas-phase reactor cores. These throw radioactive waste down their exhaust streams even when they're operating as designed (which is fine in the vastness of space, but less appealing if they're used for surface-to-orbit launches). If these designs go wrong, the main contamination will go the same way, though a reactor explosion is likely to damage the ship too. Other designs for space drives, such as some types of nuclear pulse propulsion, result in every ship's captain effectively having access to a supply of small nuclear bombs.

Realistic spacecraft must deal with cosmic rays. Everyone aboard will have their radiation doses tracked even if they aren't directly involved with the ship's nuclear power plant. For details, see **GURPS Spaceships 5: Exploration and Colony Spacecraft**.

MAGICAL WORLDS

The world of *GURPS Technomancer*, where the effects of modern technology are largely produced by magic, offers demonic complications in addition to the standard dangers.

Reactors aren't just carefully engineered systems; they have to be protected by magical defenses, too. More complexity means more points of failure and more complicated problems; a conventional accident can damage a pentagram, or a magical containment failure can cause problems in the conventional system. Perhaps the fallout is magically mutagenic, or the area becomes contaminated with death-aspected mana. And just what *were* they "breeding" in that breeder reactor?

More generally, the concept of radioactive contamination can be applied just as well to invisible pollution from magical accidents or even high-powered spells – it spreads in the air and water (and perhaps along ley lines), but it's not infectious like a disease. Some parts of it decay fast (summoned demons get bored and go elsewhere), while other parts can cause trouble for generations.

In a setting with magical symbolism, nuclear power is certain to be symbolic of *something* – whether it's elemental transformation, access to the secrets of the universe, bound demons as distinct from the loose demons of nuclear weapons, the cyclic creation and destruction of the decan Arôtosael, or merely a source of magical power. Any of these will lead to magicians trying to get direct access to it, doing dangerous things for reasons that make no sense to the uninitiated. Maybe some of the plant's staff are secret magicians already.

OBSTACLES

A radiation leak can be of any size which the campaign needs and with any specific effects that are required. It's entirely plausible to release just a radioactive gas cloud that'll disperse in a few days, rather than contaminating an area for a lifetime.

A leak doesn't need to be the primary focus of an adventure. Convincing and credible rumors of leaks, or the real thing, will lead to travel restrictions and vastly increased presence by the police and other emergency services. If that's where the group needs to go, that's a problem. The cops will be on edge and aware of the possibility of idiotic thrill-seekers (and their camera drones). Law enforcement may even think it's better for someone to be shot quickly than to die slowly of some obscure cancer.

Meanwhile, other police functions will be allowed to slide for the duration of the emergency. Nobody's going to be handing out speeding tickets or responding to burglar alarms when they're all busy keeping sightseers out of the hot zone. Villains who are planning a robbery might get everyone out of the area by faking a major leak, or making a convincing claim that they can produce one.

Of course, if your real adventure is dealing with giant mutant animals, a radiation leak can make a convenient excuse to get them there.

WEIRD RADIOACTIVE DISASTERS

As with "toxic chemicals," nuclear power and weapons have been used in fiction as the excuse for all sorts of unnatural dangers.

Zombies arise when the higher functions of human brains are rotted by radiation, while the simpler drives still work. It's surely only a short step from radiation preserving dead tissue to full-blown reanimation. Such creatures might be immune to more radiation, or especially vulnerable to it. In 1935's *The Phantom Empire*, the dead could routinely be restored to life by use of . . . radium! **GURPS Zombies** has much more on this topic, particularly the radiation ghoul on p. 91.

Giant mutant animals or mobile and carnivorous plants are something of a cinematic staple. Moving down the size scale, a super-plague could be caused by a mutation of a normal virus or bacterium.

RADIOACTIVE TERROR

Radiation scares people. In **GURPS**, people need to make Fright Checks (pp. B360-361) whenever confronted with potentially hazardous situations. Sudden vomiting may be interpreted by the unwary as a sign of radiation sickness . . .

Warning klaxons or a personal dose alarm going off, or a Geiger counter starting to click quickly, call for a Fright Check at -1. Realizing that the level is high enough to be dangerous gives -2. Realizing that it might be *fatal* gives -4. When a release reaches a catastrophic level, the check is at -6, down to -10 for a *global* catastrophe. Those without relevant skills may *start* at the -4 level ("any radiation might be deadly!").

Moving up, the next stage of human evolution could be kicked off early, perhaps manifesting as supernaturally intelligent or psionic children. See *Superhero Origin Stories* (pp. 13-14) for some additional ideas.

Any sort of Fortean phenomenon other than the blatantly occult could also be blamed on a radiation release: strange weather, outbreaks of mental illness around a particular time or place, odd lights in the sky, and so on.

ADVENTURES

Two basic forms of adventure can center on a potential radiation leak: the sort that regards a major release as a bad ending, and the sort that starts with the leak happening and goes on from there. Very few stories span the transition from one to the other, particularly since completely different teams of people generally focus on the prevention of accidents and the cleanup after them. Adventures based directly on real events are probably either anticlimactic or career-ending. Nuclear safety culture regards *any* release of radiation above an agreed-upon low baseline as a major failure.

For quick resolutions, search for leaks using Hazardous Materials (Radioactive) or Electronics Operation (Scientific); don protective gear with NBC Suit; and make a leak safe with Hazardous Materials (Radioactive) and an appropriate Mechanic skill. Where cleanup is possible at all, it will take further Hazardous Materials rolls.

Normally, an NBC suit is built to be discarded when it is removed; cleaning it of all contamination is prohibitively difficult. Even vehicles that have taken a heavy radiation dose are normally abandoned rather than decontaminated; neutron bombardment means they will be slightly radioactive for years to come.

ESCAPE

When the heroes find out about a leak, they will probably want to leave the area. Unfortunately, everyone else will feel the same way. Expect jammed roads and ugly crowds around any aircraft or helicopters on the ground. The police will try to keep order, but they'll be worried about themselves and their families, too. If the PCs know about the problem and the public doesn't, they'll have to decide whether to reveal the truth, when to say something, and maybe whether to stay and help manage the chaos.

SURVIVE

Anyone staying in the hot zone needs a reason. Maybe they're rescue workers or someone else with a key job to do. Maybe they have some other reason, important enough to risk death.

Someone who must move around in a hot zone needs protective clothing (pp. 20-21), preferably with its own air supply, or a sealed vehicle. For staying still, a sealed shelter will do; simply staying inside a solidly constructed building, without too many people coming in and out, will protect from the worst of the particulates. Hazardous Materials (Radioactive) is the primary skill for keeping contamination out of a shelter or vehicle. When moving around on foot, Survival (Radioactive Wasteland) helps travelers stay clear of hot spots.

Power and water supplies are likely to be cut off or untrustworthy. Those who have time to plan will stock up on the usual resources for surviving off the grid: air filters, water storage, batteries, chemical toilets, nonperishable rations, and so on.

Adventure Seed: Puncture Test

A terrorist group is trying to steal nuclear material to build an R-bomb. They attempt to hijack a waste shipment in transit. During the ensuing firefight, someone uses an anti-tank rocket or too much dynamite, and a cask is ruptured. Now the emergency team has to deal with the contamination before things get any worse, and the battle may still be going on. Even individual terrorists trying to get away may be spreading hazardous radiation without knowing it.

RESCUE

When rescuing victims, the first priority is to avoid becoming a victim. It only makes more work for colleagues. Buddy-check protective gear, and watch the dosimeter.

The reactor site itself is now the scene of an industrial accident. Even away from the core, the site contains a multitude of hazards:

- *Fire* (see pp. B433-B434) up to around 6d per second.
- *Steam* (up to 6d burning jet that doesn't ignite anything).
- *Toxic chemicals* (see pp. B437-439, generally contact or respiratory inflicting 1d toxic damage per cycle for up to 12 hourly cycles but potentially including concentrated acids as on p. B428).
- *Electricity* (see pp. B432-B433) doing from 6d to 6d×3.
- *Structural unsoundness* (see p. B484).
- *Radiation*; see *Core Breach!* (p. 15) and *Effects of Radiation* (pp. 16-17) for long and short-term effects.

Minimizing radiation exposure is the most important consideration. Administer only the most basic first aid to keep people alive, and then get them to safety, preferably to a casualty clearing station.

Generally, that station is on the edge of the contaminated zone. Some workers will go into the site and look for people who couldn't make it out on their own. Others will deal with the victims as they arrive, either on their own feet or brought out by others.

At the clearing station, victims are stripped, and their outer clothes treated as hazardous waste, all supervised by people using Hazardous Materials (Radioactive), which may take penalties for time spent, p. B346, if processing lots of people in a hurry. Victims are then showered and scrubbed thoroughly, using the same skill.

Skill failure here leaves people still contaminated, taking ongoing radiation damage until someone spots the problem. Unless budgets are tight, usually everyone is given radiation treatment, rather than wasting valuable time selecting those who've been exposed to a high dose. Victims are then seen by the doctors, who examine and interview them. The doctors then split them (using Diagnosis+4) into the inevitably doomed; those who need more intensive hospital treatment (with damaged immune systems, they are likely to pick up infectious diseases); and those who only need emergency housing and supplies while they work out a new place to live and how to get on with their lives. Those who've left homes often had no time to prepare themselves and have nothing more than they could carry; law enforcement must deal with identity theft and other fraud, and casual violence over very small stakes, or these will become rampant if left unchecked.

Those who need medical treatment receive chelating agents (p. 20) to get the radioactive substances out of their systems, and support measures such as intravenous fluids and nutrition to keep them alive until they can heal (they will still be damaged by radiation sickness, but they are more likely to survive the experience). The immune system is usually compromised, so antimicrobials and sterile environments can reduce infection.

Some people won't want to leave their homes. Some may be plotting to make the situation even worse, perhaps sacrificing their own lives in the process.

Adventure Seed: Fallen Star

A satellite's radioisotope thermoelectric generator has reached the end of its service life and has been ejected for recovery on Earth. But something's gone wrong, and it didn't come down at the planned disposal site. Now every potential terrorist who keeps track of the news is racing to the spot, hoping to extract enough material to build his own R-bomb. Other state actors may be taking an interest, too, especially if it's come down in their country. If the good guys don't arrive first, they'll be trying to track down everyone who's taken a piece of the payload . . .

INVESTIGATE

One of the grislier jobs after a major accident is working out what went wrong. The first stage involves gathering information and evidence, which means not only surviving in the contaminated zone but also digging through the remains of the reactor core, control room, and other places that may reveal clues. Teleoperated robots can help with this; they still suffer radiation damage, but they're expendable. More gruesomely, those who've already taken a fatal radiation dose but are still mobile may be willing to assist.

With damaged and weakened structures, investigators may crack open reserves of radioactive materials that had been sealed until now, or fires and structural collapse may have that effect while they're nearby. If multiple reactors are located on a single site, the others have *probably* been shut down safely – but one classic sabotage technique is to wait for the emergency crews, and then set off a second device to attack *them*,

since an enemy may have many targets but just a few emergency crews. The cooling systems for shutdown reactors, or their power supplies, could be a principal target.

Gamma spectrometers (p. 20) and neutron detectors (p. 21) are vital. The gamma spectrum of a source can indicate what radioactive isotopes are present, and their ratio reveals how long ago an event occurred, the initial composition of the material involved in the event, and the nature of the event. A neutron detector can alert the user to the presence of transuranic elements and ongoing fission or fusion processes. A neutron *spectrum* can separate transuranic and fission signatures from fusion reactions and from most commercial artificial neutron sources. By combining the gamma and neutron information, the investigator can identify pretty much anything radioactive. Analyzing this information is done with Physics (Nuclear) – but if there's any sign of sabotage, conventional Forensics is also important. The isotope information can be used with Intelligence Analysis to determine the likely source of the radioactive material, if unknown.

PREVENT

Physical security is about as good as it gets for nonmilitary facilities. Approaches to and roads within the site include twisting routes so that an intruder can't get up speed to crash through barriers. The roads also have spike strips to stop unauthorized vehicles. Everyone coming in must show ID, which is checked every time; it's acceptable to take a few extra minutes to process people, or even to refuse to admit them if there's any doubt. Cars are given a visual search, and people on foot go through a turnstile. Of course, radiation detectors are everywhere. Power plants tend to be in isolated areas, and security forces will spot anyone hanging around the site.

As a rough guide, there is approximately one staff member per 2MW of generating capacity, with most reactors providing about 500-1,000MW, and some sites having as many as six reactors. Security staff numbers vary, but they are usually about 20-25% of the total site staff. Other staff are technical and administrative; even the administrators tend to have a technical background. Everyone on site has at least basic emergency and hazardous materials training.

Most obvious sabotage (bombs on coolant pumps and such like) can be spotted quickly, during routine checks. The control systems will raise alarms when something goes wrong, unless they have been sabotaged, too. Every motorized valve can be operated from the control room or from a locked panel by the valve itself. If that fails, there's a manual backup hand-wheel, usually behind a *different* locked panel. (The day-to-day business of reactor operation consists largely of moving around paperwork and passing out keys.) Those locks are typically the best in general civilian service, but not extra-high security ones: -5 to -8 to pick.

Even the most white-hatted heroes may come into conflict with security forces while trying to *prevent* a catastrophe, especially if they were the only ones who knew about the problem. While these are not military installations, everyone involved knows that they'd be high-value targets to terrorists, whether trying to steal material or just cause panic; strangers don't just wander around, and anyone where he shouldn't be can be assumed to be an enemy.

In the United States, private contractors, broadly supervised by the NRC, handle power-plant security. In Canada, some power producers have their own private SWAT teams for on-site deployment.

In the United Kingdom, site security and materials in transit are the task of the Civil Nuclear Constabulary, a special-purpose police force, which also has the job of tracking down materials stolen from nonmilitary sites. Unlike other British police forces, every officer is armed (with H&K G36C carbines and Glock 17 pistols), as well as being trained in the use of protective gear; they also crew 30mm autocannons aboard nuclear-waste ships between Britain and Japan.

In France, specially trained police are used – specialized police protective platoons (*pelotons spécialisés de protection de la Gendarmerie*, or PSPG) and Gendarmerie Nationale. Military forces provide security for overseas transfers.

In Russia, Rosatom has private guards, but some of them may also be active-duty military personnel (generally the Russians prefer lots of guards to the American/British approach of few guards but lots of cameras and sensors).

Indian reactors are guarded by the CISF (Central Industrial Security Force), which also deals with airports, oil refineries, and so on; reports differ, but it does not appear to have specialized nuclear units.

The Iranian program appears to use the Revolutionary Guards for all nuclear site security.

Any security force on a nuclear site will be ready to shoot intruders with only minimal warning; but all of this security can be bypassed, particularly when a long time has passed without an incident. In 2012, three activists (aged 57, 63, and 82) broke into the Y-12 National Security Complex at Oak Ridge, Tennessee, an enrichment and weapons manufacture facility. They spent several hours causing minor damage and conducting a peace ritual before being spotted and detained by a single guard. They activated sensors on their way in, but the guards assumed it was just more false alarms from wildlife, and many cameras were out of service.

CAUSE

Of course, sometimes causing an accident may be just what's needed. Most countries that have nuclear bombs already aren't in favor of more countries gaining them, and sometimes that will lead to deniable operations. Or a group of player characters might need to "prove their credentials" to the criminals they're infiltrating by doing something minor but still blatantly illegal.

Attackers have to be clever to have a chance of success. The long game isn't as much about planting bombs as about sabotaging replacement parts, especially software. While power-

Adventure Seed: Operation Black Rain

A nation is working on the construction of a nuclear bomb; they need to be discouraged. A small team of saboteurs is sent in to cause a major radiation leak, enough that the whole place will have to be abandoned – and to make it look like an accident, so that the target nation won't try again. Of course, no witnesses should survive to prove otherwise. This facility contains a power reactor, to account for any radiation detected by international snoopers, in addition to a fuel-enrichment plant and the actual bomb-assembly areas.

plant computers are kept separate from the Internet, there's still the risk of a physical transfer on USB keys or similar; that's how Stuxnet, malware probably commissioned by the U.S. and Israeli governments, got into the uranium-enrichment centrifuges in Iran in 2009-2010. One plausible software attack could vent the primary coolant without warning, so quickly that the staff would have no time to respond before the reactor melted down.

If a fight breaks out in the control room, stray bullets and falling bodies can damage control panels. There's a fair bit of redundancy, but this sort of thing will make the technicians' work harder and may even accidentally trigger an emergency shutdown. If that happens while the technicians are trying to do something else, the situation can become far worse than it was before. (Roll against the control systems' overall HT – 13-14 in a well-organized plant – to avoid an immediate shutdown. A cinematic reactor may instead start counting down to explosion.)

Elsewhere in the plant, shooting a secondary coolant pipe (typically 1/4" steel: DR 14, HP 38) can cause a steam leak (1d or more burning jet damage, in the form of scalding with no incendiary effect); in theory, this shouldn't be radioactive at all. Depending on the plant design, a primary coolant pipe (1" or thicker steel or more exotic substances, with *at least* DR 56 and HP 60) could leak high-temperature carbon dioxide or steam (start at 5d burning jet, still without incendiary effect, and move up from there) or something more exciting like liquid metal (5d-8d of burning plus cyclic corrosion, though it's not at such high pressure and will spill like lava rather than jetting out like steam). The rupture also releases several thousand rads per hour on anyone nearby. None of these on its own should be sufficient to wreck the reactor, but if enough damage is done to the system (as it might be with four or five separate pipes taken out of action), there's a significant chance of meltdown even if the reactor is shut down promptly. Time for some rolls against Mechanic (Fission Reactor), at -4 or worse, to stave off further problems.

CAMPAIGNS

There are two main approaches to a nuclear-focused campaign: preventing disasters, and causing them.

NEST, the Nuclear Emergency Support Team within the United States Department of Energy, has a range of tasks, starting with advising police and the FBI where

nuclear terrorism is suspected (and if they should realistically be backroom technicians who don't arrest people, well, so should crime scene investigators). They can also get involved with accident investigations at power plants, or even in theory with inspection of foreign facilities.

A more cinematic team might have its own security forces rather than relying on the agency or country that calls it in, especially if it's going around the world at a moment's notice. The group also would value rare expertise in radiation hazards more than the ability to look good in a tie and keep to the party line.

If your game uses **GURPS Action**, the templates fit well into this style of campaign. The face man, hacker, investigator, medic ("health physicist"), and wire rat need only slight modification to fit into a campaign like this. The shooter, infiltrator, and assassin can be wedged in as "security," while the cleaner is an expert in containing and removing contamination, and the demolition man can *safely* remove structures that have already been damaged. The wheel man can operate sealed vehicles, drop radiation-absorbing substances from the air into a blown-up reactor too dangerous to approach on the ground, and get the team out of harm's way if things get *really* bad.

On the other side of the safety divide, a campaign could be based on a covert team which denies nuclear technology to "rogue" nations when diplomacy has failed. It might operate under the auspices of the United Nations and International Atomic Energy Agency (IAEA), or for an informal collaboration of countries which already have nuclear capability. When a project is already marginal, all the team needs to do is cause some unexpected shutdowns to delay work and increase costs. If the situation is more serious, the group can set up a full-blown disaster, permanently contaminating the site and killing key personnel.

MAXIMUM CREDIBLE ACCIDENT

Nobody's likely to run a campaign about power-plant workers, but an inspection team could easily become involved in tensions between keeping a plant running and shutting it

down for maintenance. The pull of profit against safety is a standard story and something of a cliché, but it still happens. For a bit of variety, change the stereotype around. Maybe the timorous technicians are wrong and the plant *is* safe, but one of them is going to snap and *prove* that he was right with those warnings all along . . .

Unless the players switch between characters, it would be unusual for a campaign focused on a single organization to deal with both the run-up to a major radiation release and the post-release events. The realistic inspection team may escape from the accident only to find themselves fighting for their *political* lives, with people asking why didn't they do their job and keep people safe.

*When the air becomes uranious,
We will all go simultaneous.*

– Tom Lehrer, "We Will All Go
Together When We Go"

APOCALYPSE NOW

For multiple major radiation events to happen at once, there must be a provoking factor: apocalyptic but highly competent terrorists, nuclear war, or highly energetic weather patterns which will cause catastrophe in themselves. As a cinematic alternative, physics research could go bizarrely awry (perhaps the Large Hadron Collider somehow disrupts nuclear forces), technologically adept villains build mad-science devices, or advanced aliens or crosstime agents are determined to stop people from using nuclear power even if that means wiping out the target world.

Cleanup crews will find themselves dashing from disaster to disaster to deal with the worst problems, with no time to consider the underlying cause. This is a grim campaign, unless there is some way to find out what's *really* causing everything and do something about it.

For a look at the timescales for the decay of abandoned nuclear plants and weapons, see "Nuclear Legacy" in *Pyramid* #3/88: *The End Is Nigh*.

REBIRTH IN FIRE

The more large-scale radiation releases happen, the more the world starts to look like an optimistic version of the world after a limited nuclear war: large contaminated zones, small communities of people who are suspicious of strangers who may be carrying invisible contamination, and weird mutated wildlife. Once enough farmland becomes unusable, cities will be abandoned even if they haven't been contaminated. Post-apocalyptic books, movies, and TV shows are good sources here, as well as several **GURPS** supplements; see *Bibliography*, p. 29, for some ideas.

Campaign Seed: Arrow Breakers

Some timelines have advanced past the point where nuclear technology is a political problem. Most are nowhere near developing it. But some are in that dangerous spot in the middle. A team of Special Operations (**GURPS Infinite Worlds**, p. 14) or ISWAT (**Infinite Worlds**, pp. 18-19) agents with specialist training goes from world to world covertly shutting down nuclear developments, at least until other Patrol units can stabilize the political situation. Sometimes, they must deal with other outtimers importing bombs or power systems for their own purposes. A parallel with a current date billions of years in the past will have *naturally* enriched uranium, a tempting target for any crosstime bomb builders.

Campaign Seed: The Men from the Company

The player characters are a troubleshooting team dealing with turn-key reactors (p. 6). They have to head around the world into a variety of places off the grid, to deal with customer complaints and minor malfunctions, then find themselves enmeshed in local politics – is that contamination really from the reactor, or are the locals trying to shift the blame for something else? Who gets to decide how the power is allocated among the locals? What happens when the rebels overrun the reactor site, planning to strip it down and build an R-bomb?

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He had never seen a "Fallout," and he hoped he'd never see one. A consistent description of the monster had not survived, but Francis had heard the legends.

— Walter M. Miller,
A Canticle for Leibowitz

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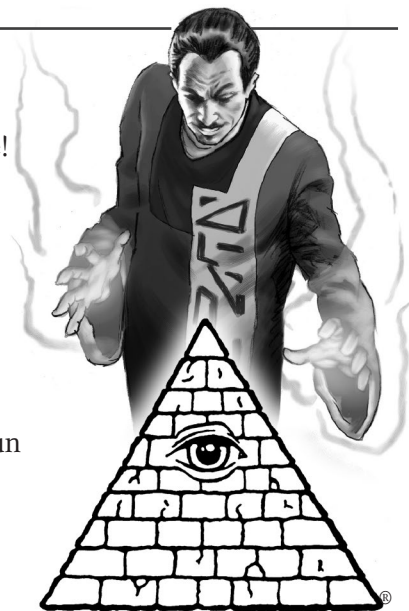
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