In this last section on radioactive pollutants, we will do a realistic dose calculation from the Fukushima nuclear power plant accident. And these dose calculations will be focused on the shorter ranges, only a few hundred kilometers at most downwind from the facility.

We're going to calculate the total dose from multiple major radionuclides that were released during the accidents. There are still many uncertainties regarding the release rates and their amount and timing. We're going to try to do as realistic a calculation as possible. So similar to the previous calculation for iodine 131, we have prepared some files that you can load to get started. And then we will go over the configuration in more detail.

So to start press the reset button and from the tutorial/Japan directory, load the dose CONTROL and setup files. And unlike the last example, select the setup file, and then things will load properly. So what's different here is let's move to the set up menu, and we're still going to focus in on the 24-hour period that contained most of the emissions, however, unlike the iodine calculation, we're going to need to start the calculation at the time of the accident, at the time of the earthquake, and this is when the reactor shutdown, and the fission processes stopped. Because the published emission inventories are, have all been back corrected to the time of the accident, or the time that fission stopped. And this time then will be the start of the decay process for the radionuclides. So published source values are valid at this time and any time after that the emission values, or the

concentration values would be decay corrected from this time.

We're going to start again from the location of the Fukushima plant and also using a nominal hundred meter height. And we're going to want to cover the period of the emissions, which in the previous example, we know the reactor number two explosion occurred on the 14th at 12 UTC, so we want emissions to occur for that 24-hour period from the 14th through the 15th. So to run through that period of emissions plus an additional, let's say 12 hours to get all the material far enough down wind, that it is not going to affect the near source or the local area dose, we're going to run the calculation for 108 hours. We're also going to use the half degree data so this is the GDAS data from the 11th through the 22nd.

And now open the pollutant menu, and notice that we've defined two pollutants. Now in the fission reaction, any fission reaction, over 200 radionuclides are created. We're not going to track all of them, but we're going to configure the model to track two surrogate pollutants, each surrogate will represent multiple radionuclides. And these two surrogates are, one will be a particulate radionuclide and we're giving it the abbreviation of RNUC, and we're going to use a unit emission rate, we are not going to define emissions at this point. And we're going to have a 24 hour emission period that's going to start on the 14th at 12 UTC.

And the second pollutant will be a noble gas. It will also

have a unit emission rate for 24 hours starting on the 14th. So that was relatively straightforward. And from those surrogate pollutants in the post-processing step, we will apply the emission factors for each radionuclide that applies. There could be multiple noble gases and there could be multiple radionuclides that we are following. And each one will have its own radioactive decay which would have started on March 11 at 12.

We will set up a concentration grid again similar to the iodine calculation, 5 km resolution, well not similar, not one degree but 5 km resolution. So it'll be relatively high resolution and only covering a 10° domain. And we can leave the same two levels, one for deposition and one for air concentration, covering the average in the lower part of the boundary layer. And we're only going to do one averaging output period to keep the computations relatively simple. We want to find out what the dose is for this period, starting on the 14th when the emissions started, covering a 36 hour period. So we give time for the last emissions on the 15th at 12, we give it another 12 hours, to depart the computational, or the concentration grid area.

Now for deposition, since we defined two species, we need to define two deposition configurations. So for the radionuclide, what we're going to do is we're going to configure it like we would configure cesium 137, as a particulate with a 10th of a centimeter, as a particulate with the 10th of a centimeter per second settling and dry deposition velocity, and both wet in-cloud and below-cloud

wet removal. However, we do not want to define any radioactive half-life, because we are going to assume that all the radionuclides, all the particulate radionuclides that were released, will have similar deposition characteristics as cesium 137. This may or may not be true, but it is an approximation that we will make to simplify the calculation. And as I said, we will apply radioactive decay after the computation has completed. And then the second species is the noble gas, which has all zeros, because it has no deposition.

So once we've made these changes, we should take a look at the name list file, and what we did there was, we set the particle release rate, well we're doing 3-D particle and we set the particle limits, so that we're going to release over 24 hours, one, 500 particles per hour. So this case, it's a thousand particles per hour, not 500 particles per hour, so that's the release rate. We're releasing over 24 hours and we're releasing 24,000 particles, so we would be releasing 1000 particles per hour. And we're making the maximum just little bit larger.

And we're going to do one other thing, one other thing here, is in the in-line chemical conversion module menu, we're going to set the mass dimension to two. That means that each computational particle that is released will have two mass elements. The RNUC mass element, the particulate radionuclide and the gas, the noble gas element, both will be tracked on the same particle. So this is a simplification to reduce the number particles that are needed because the particulate, the cesium surrogate,

the surrogate particulate is so small, we're assuming it has similar transport and dispersion properties as the noble gas. And the vertical redistribution through gravitational settling will be negligible. So we are going to save, and save again to close the menus and now we run the model.

So while it's running what I would like to point out is the computation at this point only includes two species. In the post processing step, we're going to create multiple species, and the way we do this is by defining a source term and a radioactive decay for each species that we want to use in the dose computation. And to do this I'm going to open up for now the batch file while it's running so you can see the computational steps. Because when we do this through the graphical user interface, it will not be apparent. So this is the first part, where we set up the CONTROL file for the calculation, and we set up the two species here, the radionuclide and the noble gas. And I notice here we have it for 12,000 not 24,000 so there's an inconsistency in the documentation. And then when this is completed, when this is completed, we're going to create this file called activity.txt. And this is created by the CON2REM program and then using that activity.txt file, the CON2REM program will create the dose file using the various switches. So this will be the post-processing step that we will do after the simulation completes.

And this activity.txt file, and there is a sample of that in the Japan directory, bear with me for a moment here. So right now it's relatively simple, and the file that we will use for the Fukushima calculation contains the top 10

radionuclides that contribute to the short-term dose. And in this file contains several columns. The first column contains the half-life of the radionuclides, in this case is in seconds, and you can see that some of the half-lives are fairly short. For instance there is iodine 133 and xenon is also relatively short. And then there are of course some longer-term radionuclides like cesium 137. So clearly if we were doing this calculation and we are interested in long-term dose, we would have a different list of top 10, because the short half lived radionuclides would have decayed and would be no longer important. So these are the ones for short-term.

The other columns here are used for other applications relating to nuclear detonations, but for now, for a reactor accident, these columns are all the same, and in this particular application they represent the maximum three hour emission rate of that particular radionuclide that was observed during the Fukushima accident. And then we have the cloud-shine and ground-shine dose conversion factors that are used in computing the dose. So the cloud-shine is used for air concentration and the ground-shine for deposition. And as you recall we have those numbers that we used in the previous example for, in the first example for cesium, if you recall. We're not doing inhalation in this particular computation. And the other point I want to make is that, for instance xenon is a noble gas and it has no dose conversion factor for ground-shine because it does not deposit, all these others deposit.

So what happens in the CON2REM program in the post-processing step is that the dispersion factors, the dilution factors, are multiplied, that is the concentration output from the model using a unit emission rate, is multiplied by the source term to obtain an air concentration, and it is also decayed by the half-life, to give us that air concentration at that particular sampling output time which is then multiplied by the dose conversion factor to give us a dose for this radionuclide. And the same calculation is done again for this radionuclide, going down the list, except for xenon, xenon is a, well it's done for all of them, in terms of cloud-shine because this represents the concentrations. And it is only, it is done for all of them except xenon for the ground-shine, for the dose from the deposited materials.

And in this post-processing environment then the subsequent doses, so in other words the product of the source term times the model prediction, times the dose conversion factor then, are all added together for all the species to give us a total dose, and a total dose from cloud-shine and a total dose from the ground-shine. And that's how the post-processing does a complex radiological simulation using multiple species. This activity.txt file can have as many radionuclides as you like. We can be processing all 200 of the fission products that are the result of nuclear reaction. So this is the file that gets generated.

Close this, we're almost to the end, and again I'm going to go ahead, and so when the model simulation has

completed, what we're going to do is we're going to go ahead and open the utility, Convert to Dose program and, menu rather, and this menu will create an activity.txt file if one does not exist in the working directory. And you can create one for a nuclear detonation or a reactor. The nuclear detonation activity.txt file will create one with all the fission product radionuclides and this one will just create the top 10 based on the Fukushima accident and that's step that we're going to take. And now in the HYSPLIT working directory, we have this activity.txt file, which is the one I just discussed. As an example, if I create one for detonation, it's still the top 10, but it's a slightly different, a different configuration.

In any event, create reactor, this is what we want. Make sure we have a clean file here, and we can edit the file if you want, we can not so much edit the file, we can customize the computation. So if the default is to set it at the fraction of the Fukushima accident maximum, but you can set it partly or a fraction of it or multiplier of it. In a similar way there options for a detonation but were not going to discuss that in this example. And then the output will be written to a file that can be plotted in the concentration plotting program. And we're going to have an output of concentration rather than, sorry we're going to have an output of dose, rather than concentration. If you were to select concentration, what we would be doing is we would be generating an output file with each of the species that are in the activity.txt file. So if we had 10, nine radionuclides and a noble gas, the input file has two species, that is RNUC and NGAS, but the output file would

have 10 species of concentration representing each one of those radionuclides. That is the unit emission times the source term decayed from the start of, the end of fission, at the time of the earthquake. And what we want to do is we want sum all the species together to get the total dose rather than say individual dose.

Again to read some, you can get more information on the switches by going to the help file. Instead of a dose rate, which we might want if we were looking at time varying output, we just want the total dose, in either REM or Sieverts. But this time we're going to output in Sieverts and the reason for this is the verification map that's been published is also in Sieverts. And we do want to apply decay and we're not going to apply any extra decay. And what I mean by that is that if you want to know what the dose will be a year from now rather than after this 36 hour period. So you could add an additional year's worth of decay to this computation. So once the calculation is completed, and we're almost there, you're going to press the plot dose button.

I should say also that the information on the accident is posted by the Japan nuclear regulation authority, and there is lots of information online. And they may even have, going back to the original accident, results available. So let's take a look at the final result. And like I said we created the activity.txt file. We're going to create this output file with the dose. It's a pretty simple step and now we're going to plot the dose. And you can see in this first calculation, this is the airborne dose, and the numbers are

relatively small, well not that small, a milli-Sievert is equivalent to about one REM per year, but this is the airborne dose, which means that it blows away, so you're only being exposed to this milli-Sievert, I'm sorry 10 mSv's is equivalent to one REM, so one milli-Sievert is, it is actually a fairly large value.

The next frame, this shows actually to be over this 24 hour period the winds were changing with time, in a clockwise fashion, and then in the next frame you can see the resulting deposition pattern with the peak deposition being 23 mSv right near the source location with lower values, obviously going, the 20 mSv line goes fairly far downstream here. So how does this compare. So remember and I said that the one year REM equivalent was about 10 mSv, so the twenty-three mSv means that in that downstream region here, so in the yellow-green area here, so in the this 36 hour area, so in this 36 hour period, the people are exceeding their annual dose within essentially a day, so that's why those areas were evacuated.

Now how does that compare to the measurements. One published map here shows concentrations, I'm sorry, doses, now this is a year later, some of the short lived products have decayed, but we're seeing doses on the order of 100, 200 milli-Sieverts. So the model is still under-predicting a little bit, but the point is that we only looked at one 24 hour period of emissions. So that was the period with the greatest emissions, but emissions occurred, significant emissions occurred, for a couple

weeks. So to get the numbers like that they were showing here, the published numbers, we would really need to do the entire calculation. Now there are some other model configurations that could be used to improve this. Also remember that the total dose is going to be the sum of the air and ground components, but the air component does dissipate rapidly, whereas the ground shine component continues to contribute.

So this concludes the dose computation example and I showed you how with a very simple configuration and a post-processing step, we could account for multiple species, each with different half-lives, emission factors, and applying different decay to the air concentration and deposition amounts to get valid answers for each location downwind.

And this concludes the radiological dose computation section.