4.0 INITIAL FUEL LOADING DETERMINATION

4.1 General

Because of the on-load fuelling feature of the CANDU reactor, the overall power distribution and regionally averaged characteristics of the fuel remain more or less constant throughout the life of the reactor except for the first year or so. The reactor is, of course, initially loaded with un-irradiated fuel and hence the feature of tailoring the discharge burnup in individual channels to accomplish the desired power distribution is not available. This means that:

(a) if the utility requirements are such that full reactor power output is necessary from the beginning of operation, and

(b) the design of the core is such that some variation in the discharge burnup is required at equilibrium burnup conditions to achieve full power,

additional means of shaping the power distributions is required for the first year or so of operation.

Both of these conditions have applied in all of the CANDU reactors except for the Pickering A units and the RAPS-1 unit in India. In the former case the adjuster rods had enough absorbing material in them to do all of the necessary power shaping with the adjuster rod system alone. This means that these reactors were nominally designed to have the same discharge burnup from each channel throughout the reactor. The latter condition applied in the case of the RAPS-1 reactor, in which case it was the choice of the utility to accept less than full power output during the first year or so of the operation. Therefore, in these two cases the reactors were initially loaded with a complete charge of natural uranium fuel.

4.2 *Criteria For Determining Initial Fuel Load Characteristics*

In those cases where special treatment of the initial fuel load is necessary, a key factor is that the need exists only once in the life of the plant and for a relatively short period of time. This consideration precludes provision of extra absorbing material in the form of additional mechanical absorbing rods which would be removed as required or by additional H_2O absorbers of the type used for the liquid zone control system. The reason is that it is relatively expensive to provide the hardware associated with such devices and they would require fixed incore guide tubes which would remain as an unnecessary fixed parasitic load in the reactor. The alternative of removing the guide tubes after the reactor has operated for a year or so would demand a lengthy shutdown and present a rather difficult operation.

The most practical way to provide for the additional absorbing material is to place it in the fuel channels. There are basically two options. One is to design modified fuel bundles which have lower reactivity than natural fuel. The other is to replace strategically chosen fuel bundles with "dummy" bundles containing neutron absorbing material.

4.2.1 Fuel Bundle Modifications

The fuel bundle could be modified either by intentionally adding neutron absorbing material in the sheath or putting some type of poison in the fuel, or by reducing the fissile content in the fuel. The latter is the approach which has been used in all cases for the CANDU reactors requiring this kind of modification to the initial fuel load. The reasons for this are manifold but probably the key factor is the ready availability of fuel depleted in ^{235}U, usually at a cost less than for natural fuel. Furthermore, this approach requires no special treatment in the fuel manufacturing process, except the need to keep the two types of fuel separated.

4.2.2 Use of Dummy Bundles

There would be no problem in principle with using special bundles containing only neutron absorbing material provided they are designed to be compatible with the fuel handling system. Adopting this approach would require additional design and testing effort to develop a bundle which would meet the requirements.

4.3 Determination Of The Initial Fuel Load With The CANDU-600

Once the decision is made to use depleted fuel (fuel with reduced ^{235}U content) to accomplish the shaping of the power distribution in the initial core, the next task is to determine the number of such fuel bundles required and their placement in the reactor. In making this determination it is not sufficient merely to consider the situation when the reactor initially is started but it is necessary to examine the operation of the reactor at least until refuelling begins and perhaps beyond that. The reason is that there is a significant increase in the reactivity of depleted fuel prior to the time when the reactivity monotonically decreases. This characteristic also occurs for natural fuel but is far less pronounced.

Figure 4.3-1 shows the reactivity variation with burnup for depleted fuel having a ^{235}U content of 0.52 atom per cent and is compared with that for natural fuel. The reactivity initially rises because of the plutonium buildup with irradiation that more than compensates for ^{235}U burn-out. (The build-up of saturating fission products during the first few days of operation is not shown on this graph. They are assumed to be present from the beginning). Because of this behaviour of the reactivity of the depleted fuel, the variation of power distribution with time is significantly affected. Therefore, it is necessary to simulate the reactor operation well beyond the point at which this peaking of the reactivity occurs. This ensures that there is not a period during which the power distribution becomes peaked in an overall sense due to the behaviour of the depleted fuel relative to that of the natural fuel.

To choose an "optimum" loading of the initial core, a number of possibilities are examined in which the number of bundles, their location, and the ^{235}U content are varied. When this is done for the first time for a new core design, this survey type assessment is normally done with a 2-dimensional diffusion code because of computing costs. A code having R-Z geometry capability is best suited for this type of calculation. However the 2-dimensional feature does impose the restriction that the depleted fuel must be represented by an annular region or a central cylindrical region in which the properties of the core must be constant. Typically only two depleted fuel bundles in each channel of the central part of the reactor core are needed, because of the bi-directional fuelling feature these bundles would be staggered relative to the central diametral plane so that there would be two planes of depleted fuel each containing a checker-board arrangement of bundles within the central part of the reactor. These planes would have to be presented in the r-z model as discs having smeared properties which are representative of the equal mixture of natural and depleted fuel. This homogenization procedure tends to give a smoother flux distribution and lower peak powers than a 3-dimensional simulation would give, particularly during the period prior to refuelling. Consequently, when the survey work is completed and reference depleted fuel configuration is selected, it is necessary to perform some 3-dimensional simulations to verify that the power distribution is in fact acceptable throughout the early period of operation.

When refuelling begins the approximations demanded by the 2-dimensional model are even more serious as it is not possible to represent single channel refuelling and even if a number of refuellings are done at the same time they can be simulated only by smearing into an annular ring. This topic is dealt with in more detail in the lectures on Fuel Management[23].

In the CANDU-600 the initial fuel optimization process led to specifying two bundles in each of the central 80 fuel channels as shown in Figure 4.3-13. The bundles were located in positions 8 and 9 where the bundle positions in the channels are numbered from 1 to 12 in the direction of fuelling. The optimum ^{235}U content was found to be 0.52 atom percent. With this initial fuel loading the variation of excess reactivity with time is as shown in Figure 4.3-2. Note that the reactivity initially increases from about 16 mk to 23 mk at the plutonium peak. Figures 4.3-3, 4.3-4 and 4.3-5 show representative power distributions in the horizontal radial, vertical radial and axial directions respectively at 0 irradiation. Similar distributions are shown at 40 FPD (Full Power Days) in Figures 4.3-6, 4.3-7 and 4.3-8 and at a 100 FPD in Figures 4.3-9, 4.3-10 and 4.3-11.

The main feature to be noted is that "dishing" of the power distribution which is rather pronounced at 0 FPD flattens out with increasing fuel burnup. The maximum bundle power correspondingly decreases as burnup proceeds. It is evident from the changes that occur in the power distribution during this period of operation prior to fuelling that it is not sufficient to look only at the 0 irradiation case in order to establish the characteristics of the initial fuel load.

Figure 4.3-12 shows the maximum bundle power vs time for the first 600 FPD of operation for a typical refuelling strategy. Of course, the actual history once refuelling begins would depend on the specific strategy used for refuelling the reactor. It would vary somewhat from one reactor to another because refuelling decisions are made by the operator, on a daily basis.

Since the power distribution early in life is quite different than that at equilibrium burn-up conditions, it is necessary to assess the impact of it on the performance of the control and shutdown systems. However, the objective is merely to verify adequate performance. The design of these systems is "optimized" for the equilibrium burn-up case since that exists for all but about the first year of operation.

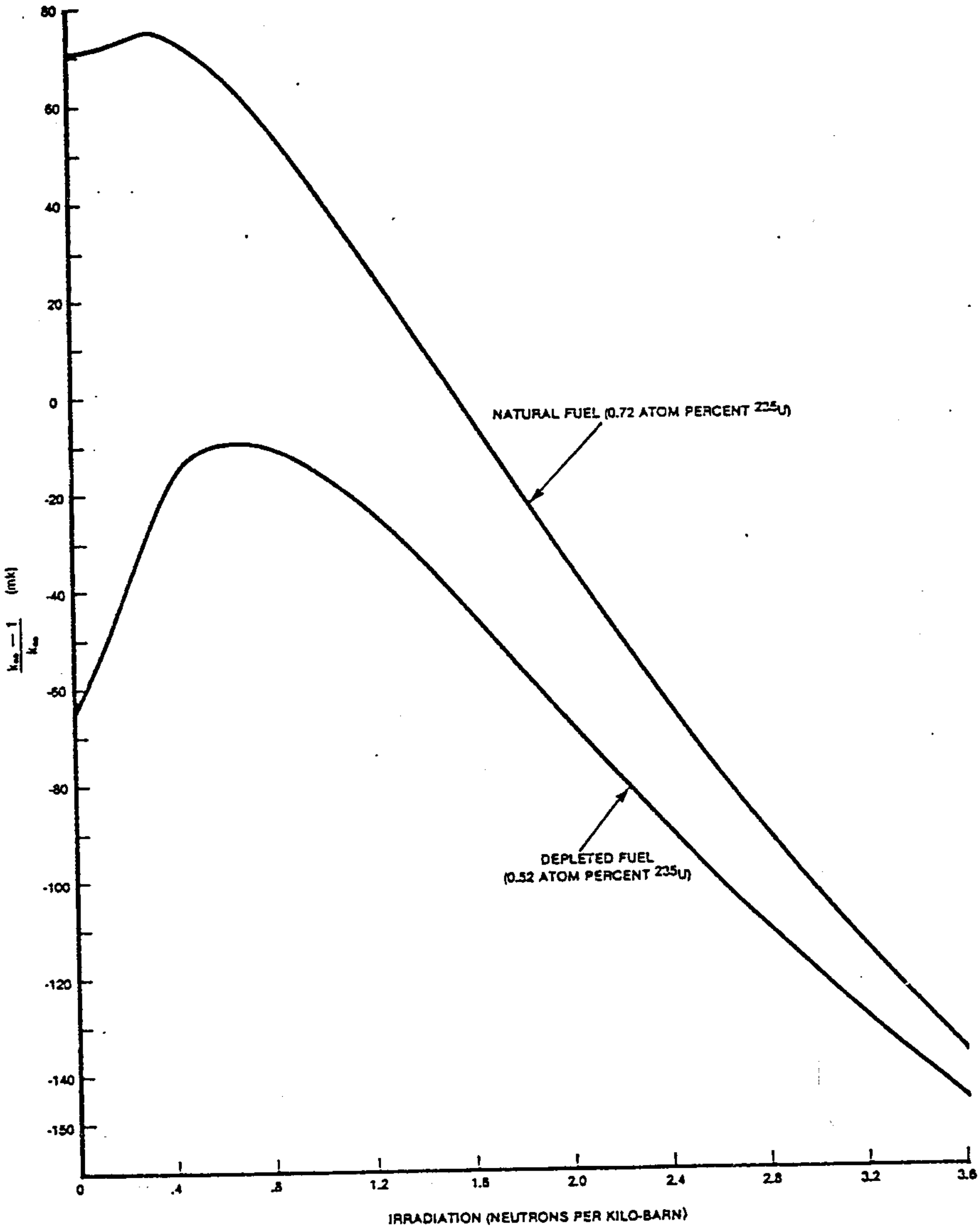

FIGURE 4.3-1 REACTIVITY OF 37-ELEMENT DEPLETED FUEL VERSUS IRRADIATION

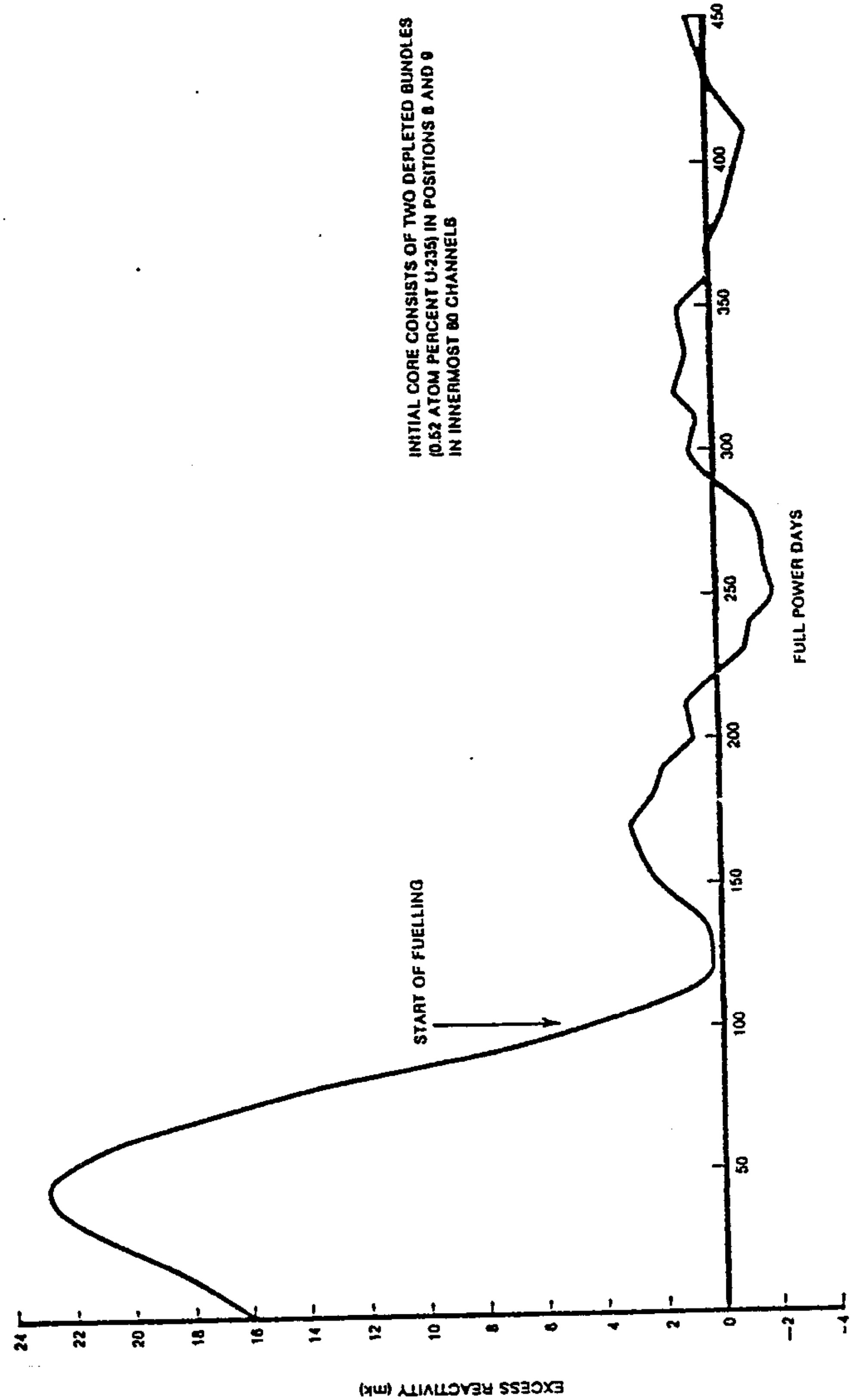

FIGURE 4.3-2 VARIATION OF EXCESS REACTIVITY DURING INITIAL BURNUP PERIOD, FMDP SIMULATIONS

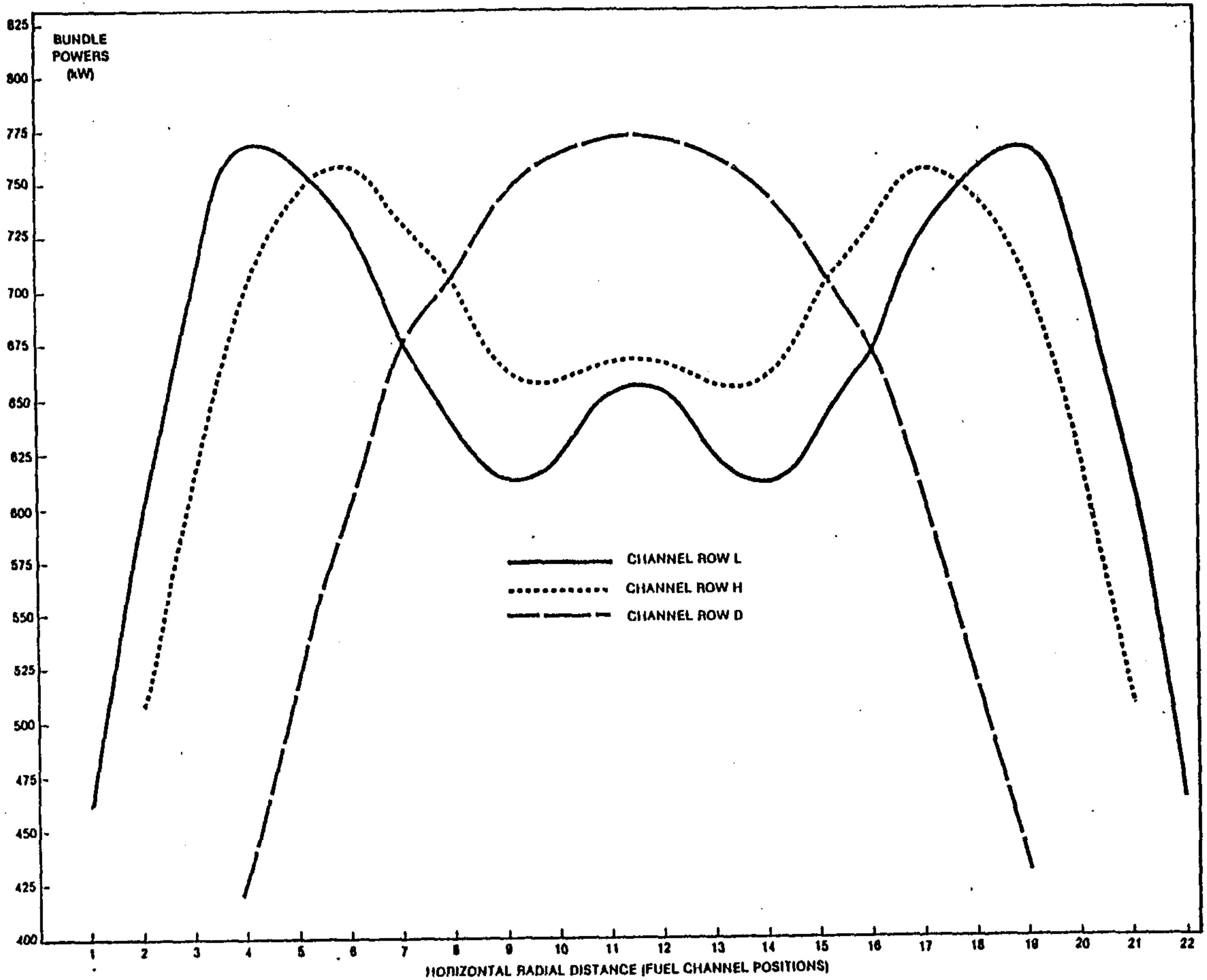

FIGURE 4.3-3 HORIZONTAL RADIAL BUNDLE POWER DISTRIBUTION AT 0 FPD

TDAI-244

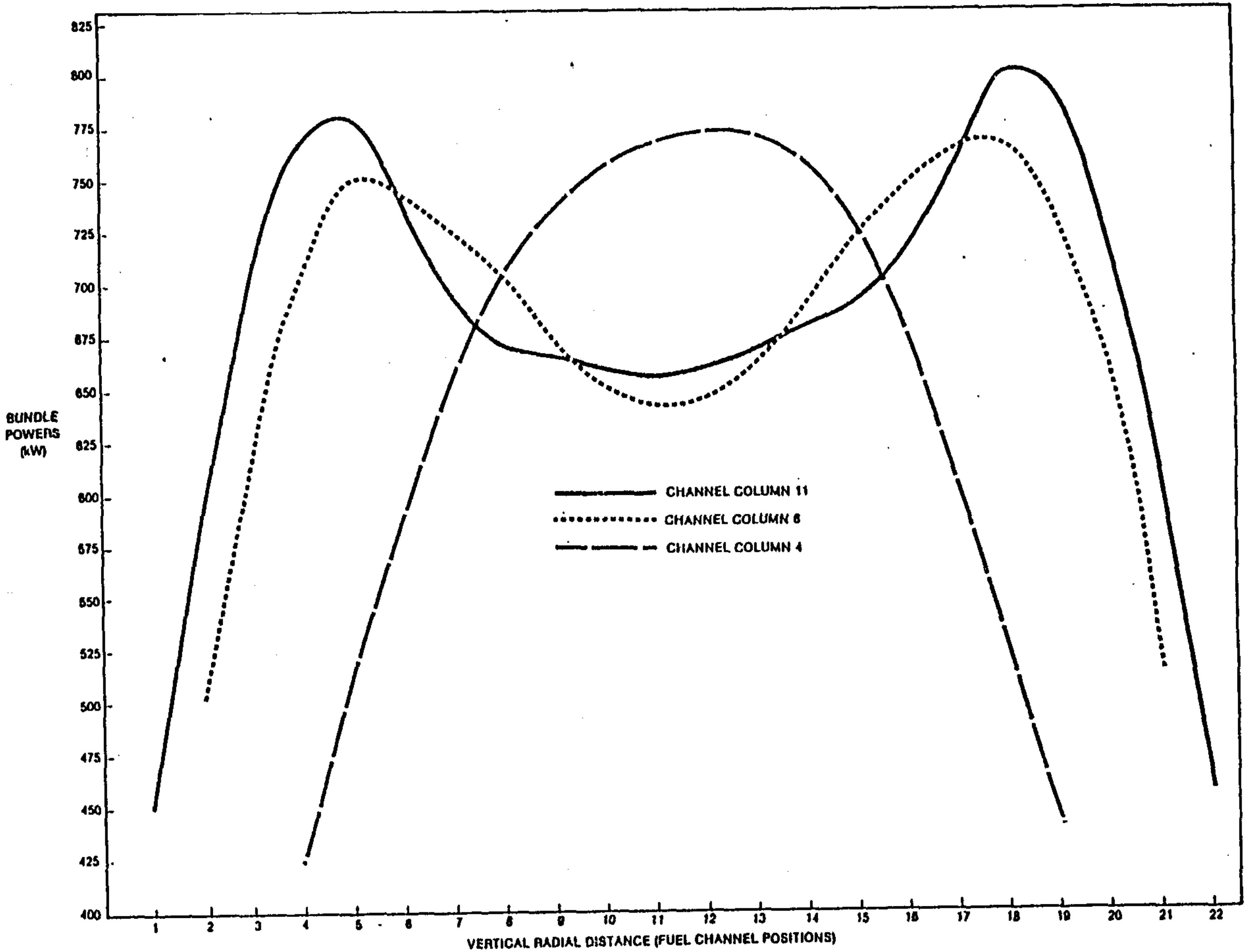

FIGURE 4.3-4 VERTICAL RADIAL BUNDLE POWER DISTRIBUTION AT 0 FPD

TDAI-244

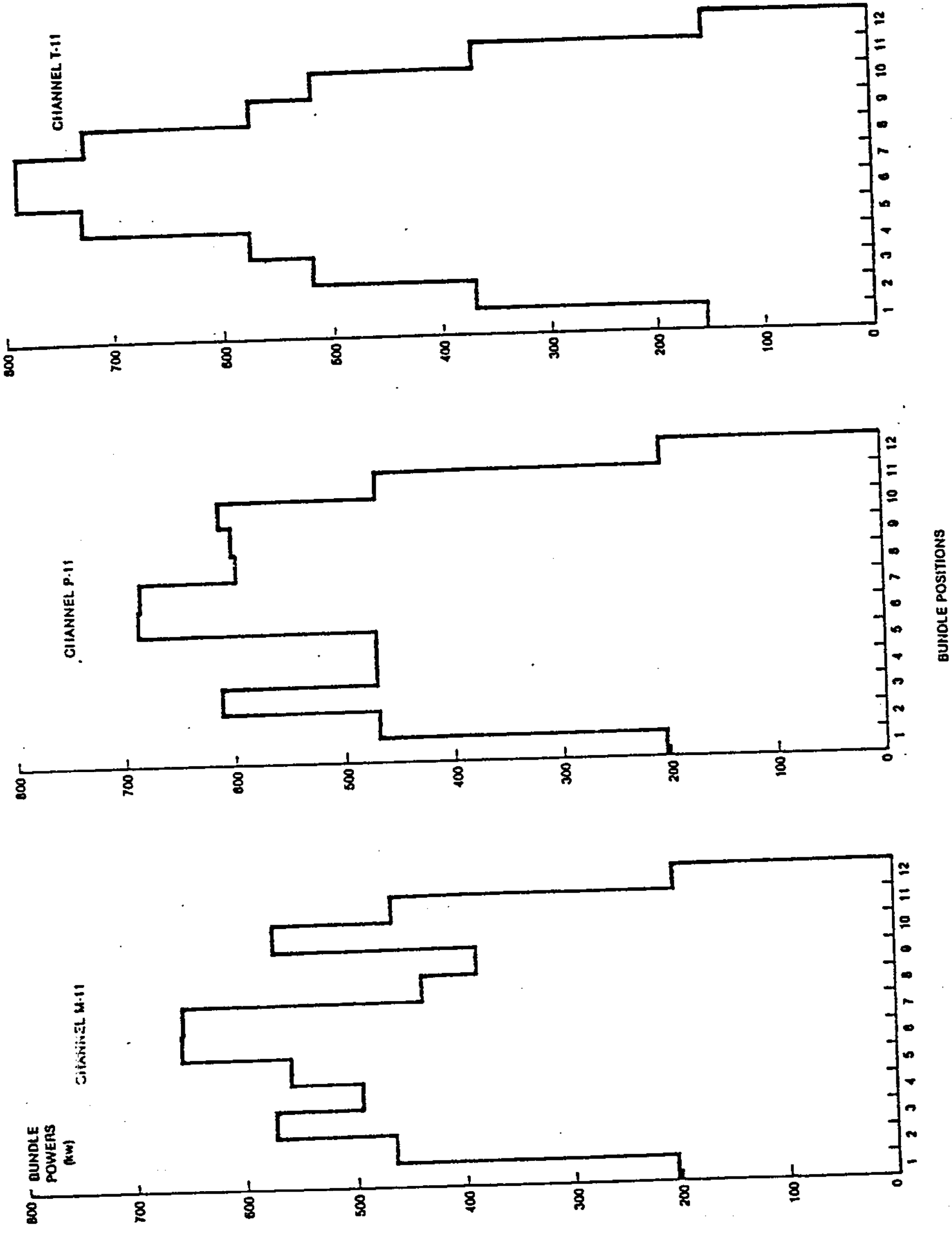

FIGURE 4.3-5 AXIAL BUNDLE POWER DISTRIBUTION AT 0 FPD

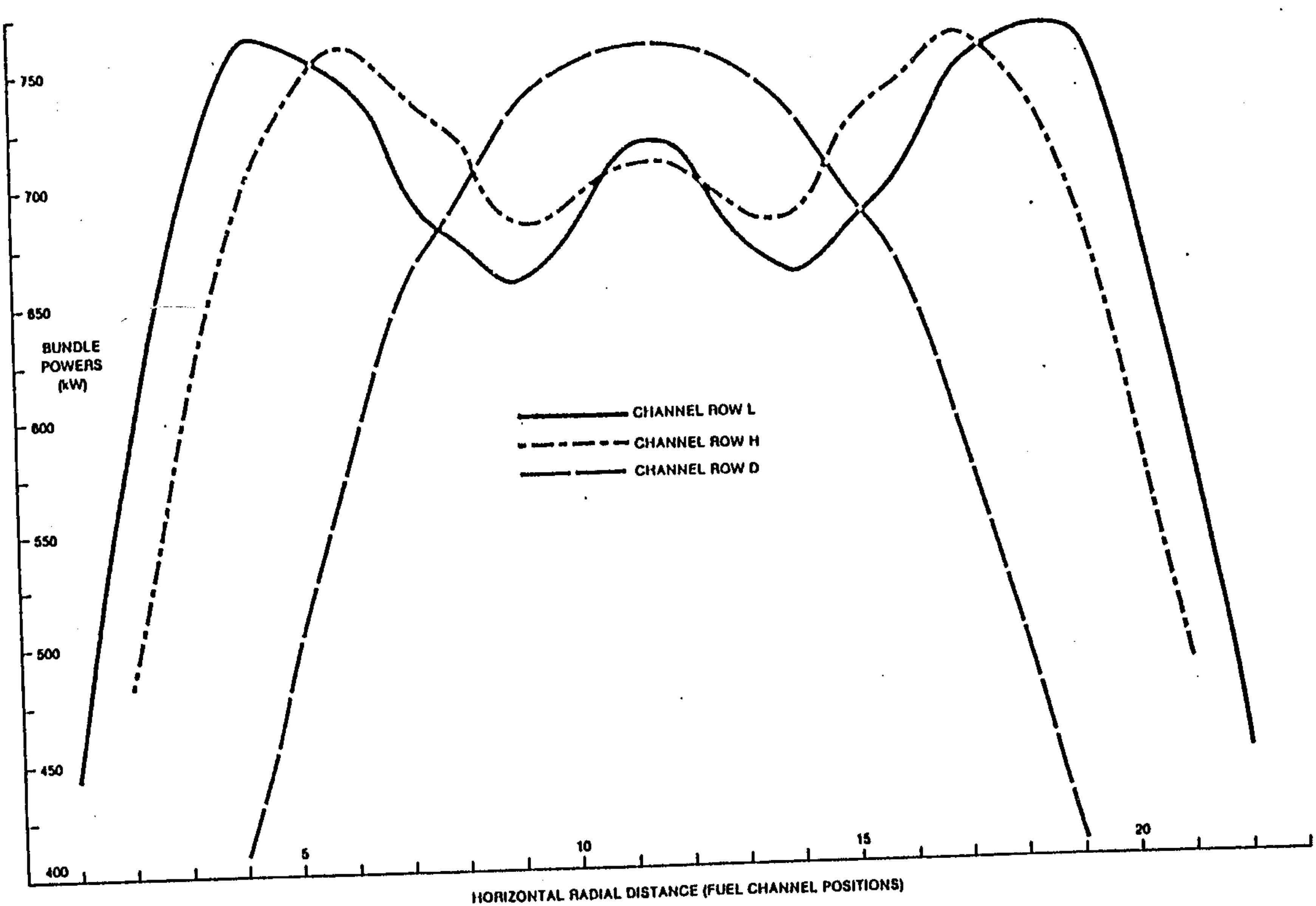

FIGURE 4.3-6 HORIZONTAL RADIAL BUNDLE POWER DISTRIBUTION AT 40 FPD

TDAI-244

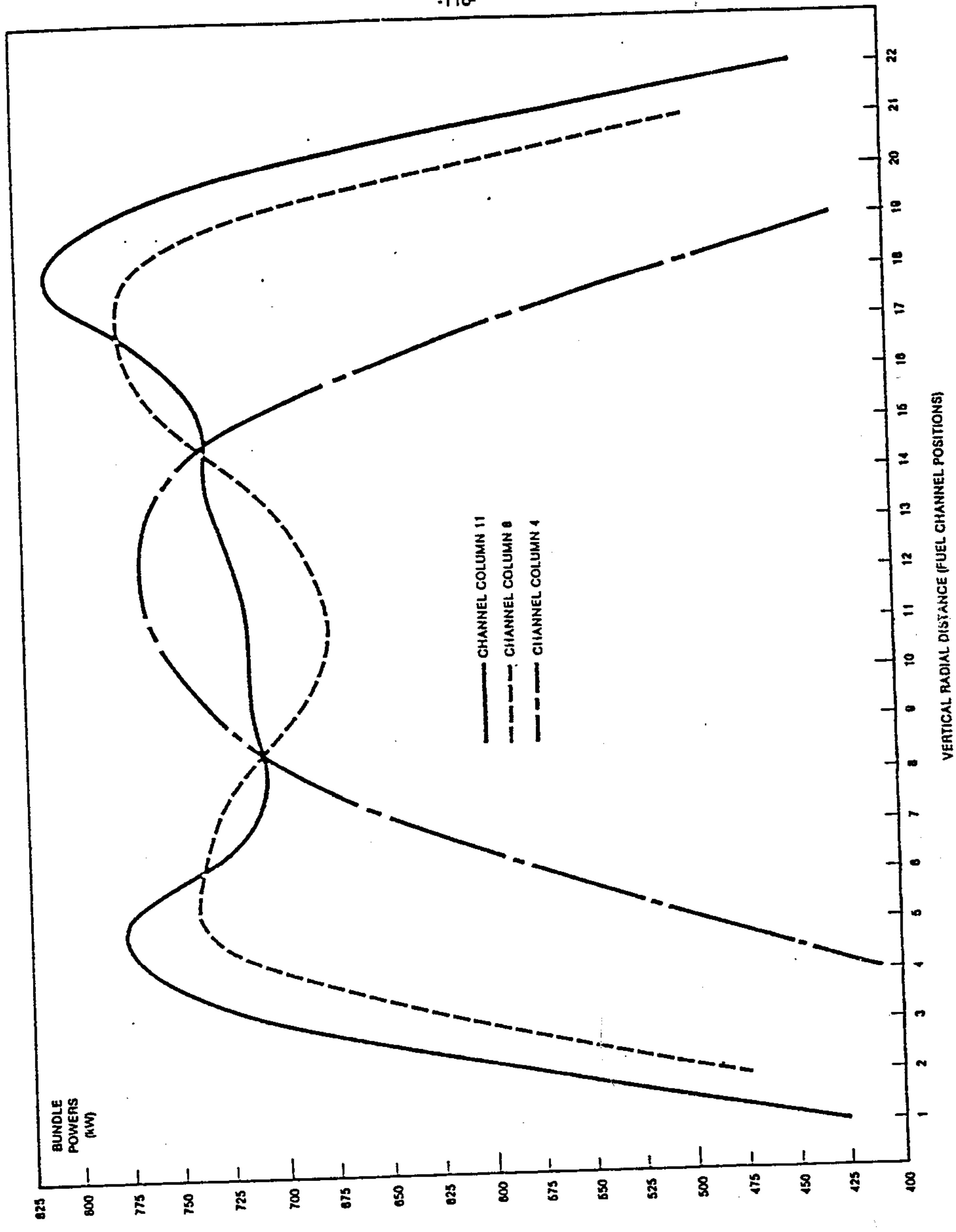

FIGURE 4.3-7 VERTICAL RADIAL BUNDLE POWER DISTRIBUTION AT 40 FPD

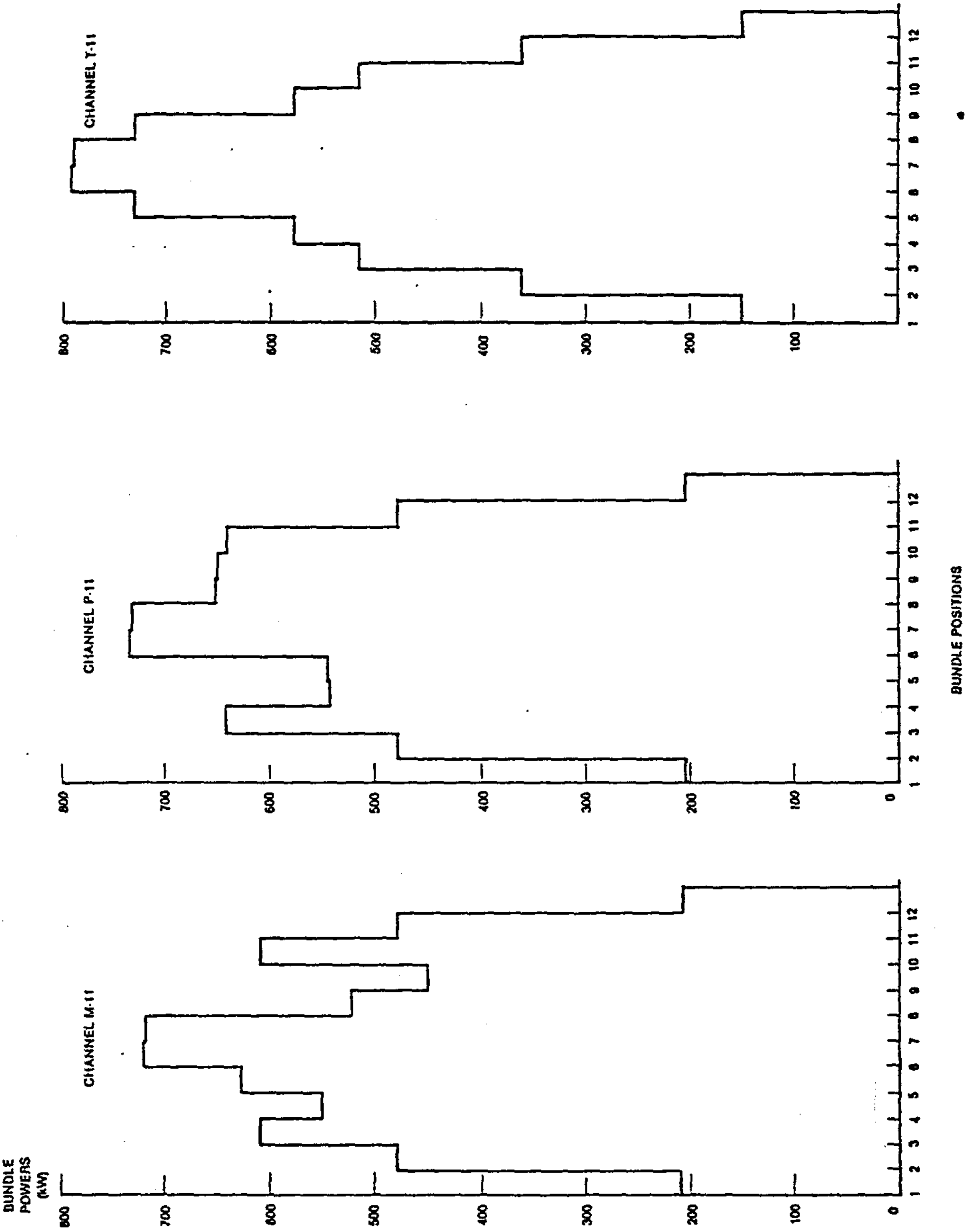

FIGURE 4.3-8 AXIAL BUNDLE POWER DISTRIBUTION AT 40 FPD

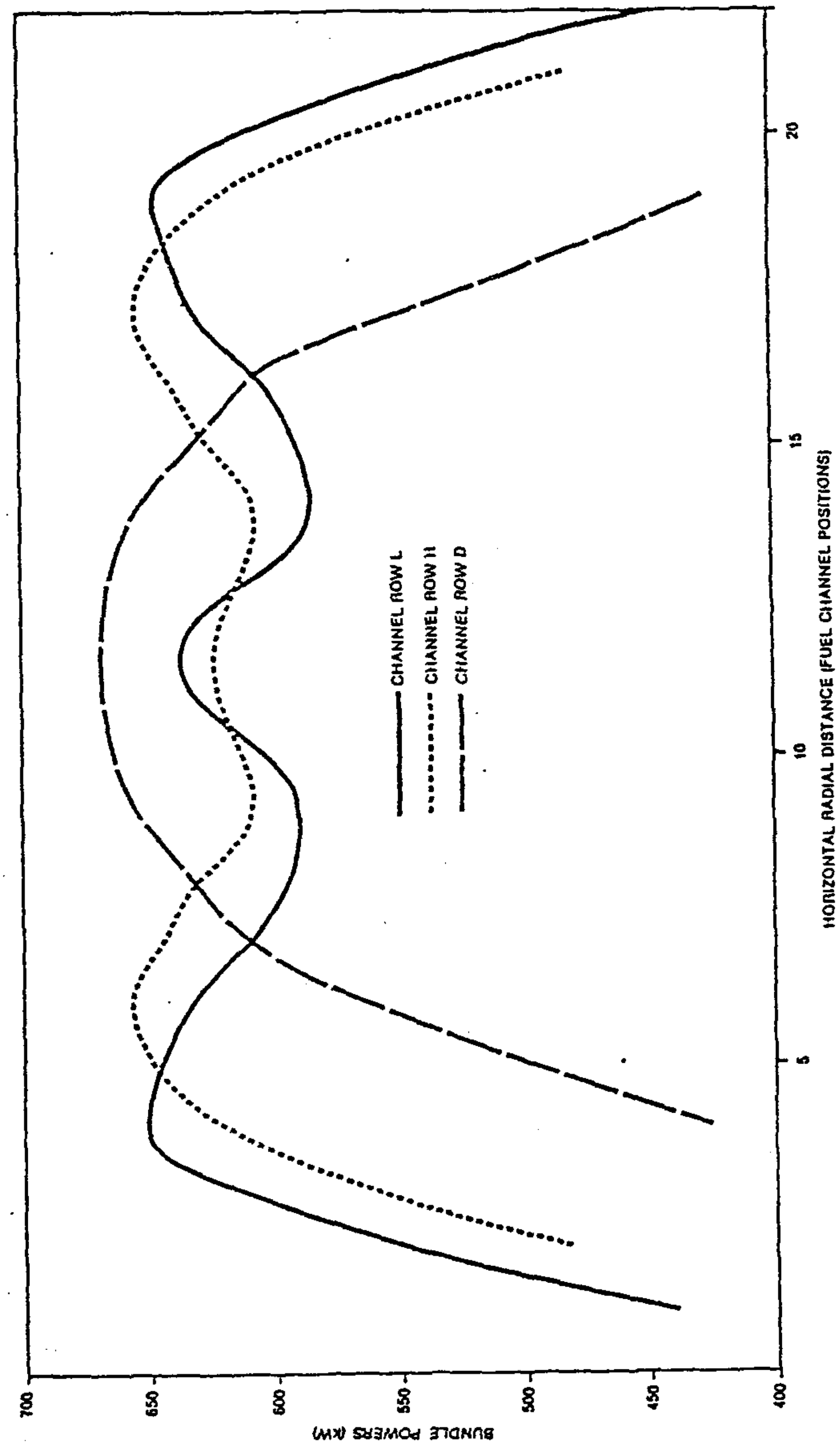

FIGURE 4.3-9 HORIZONTAL RADIAL BUNDLE POWER DISTRIBUTION AT 100 FPD

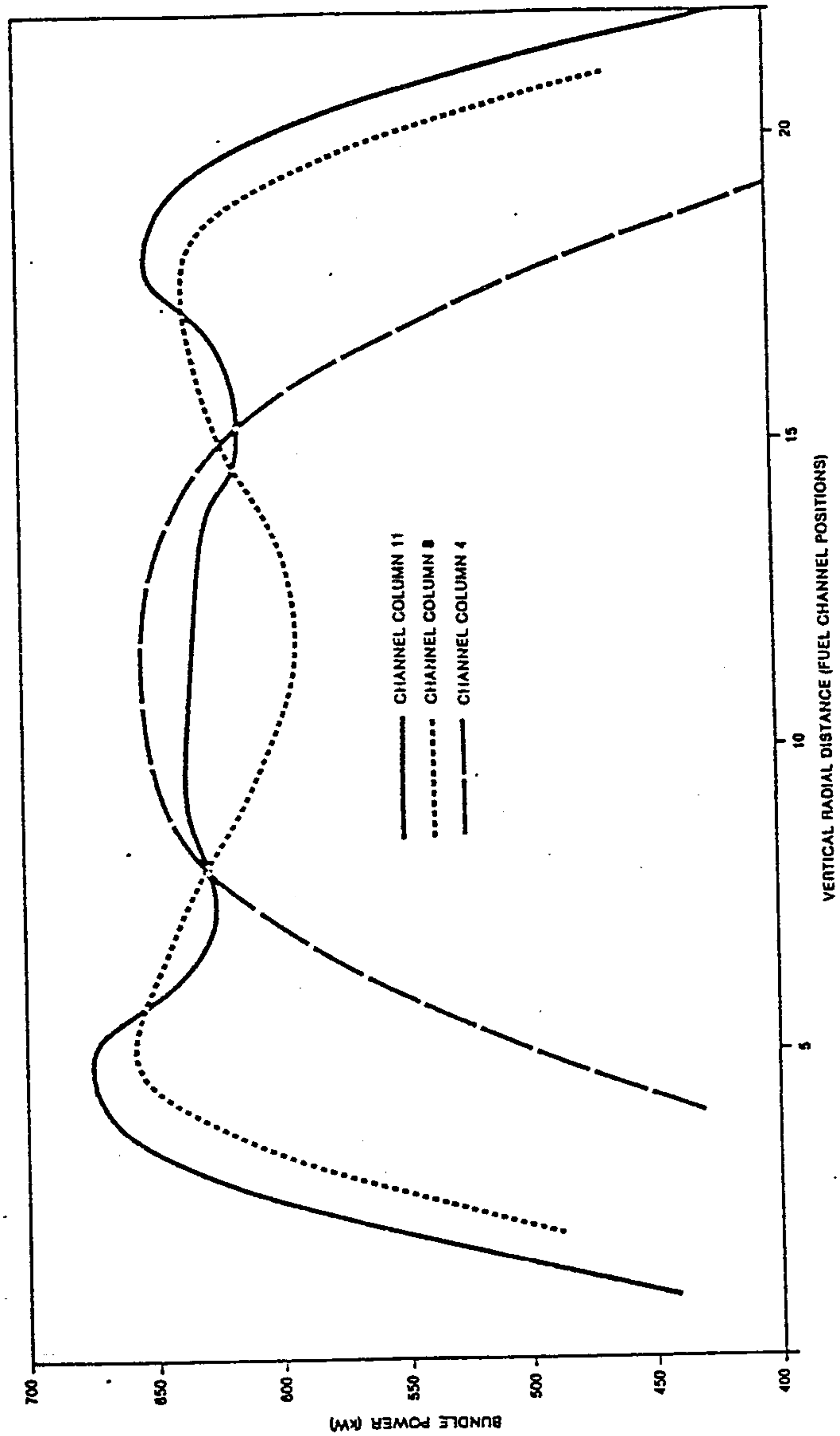

FIGURE 4.3-10 VERTICAL RADIAL BUNDLE POWER DISTRIBUTION AT 100 FPD

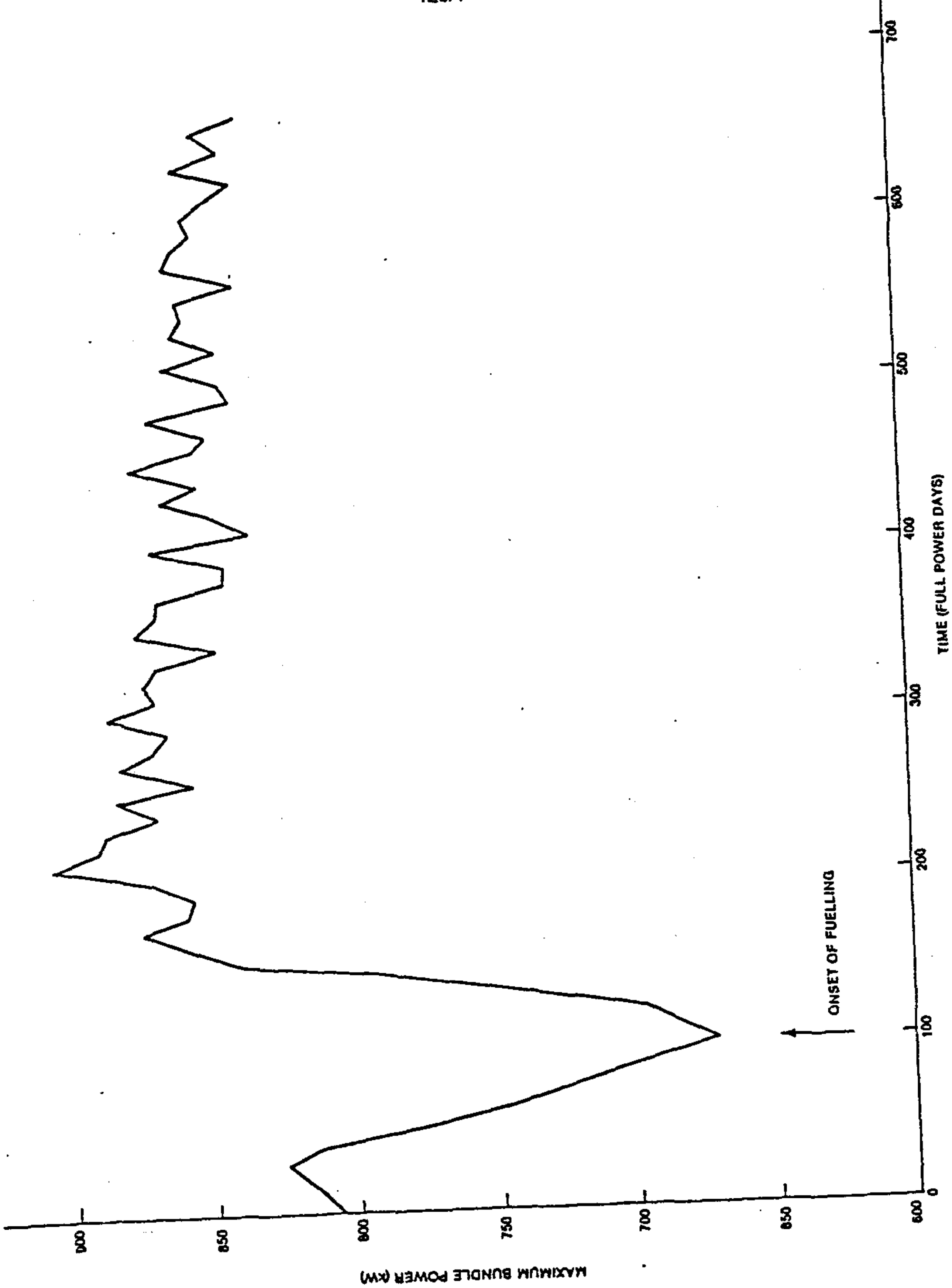

FIGURE 4.3-12 MAXIMUM BUNDLE POWER VERSUS TIME

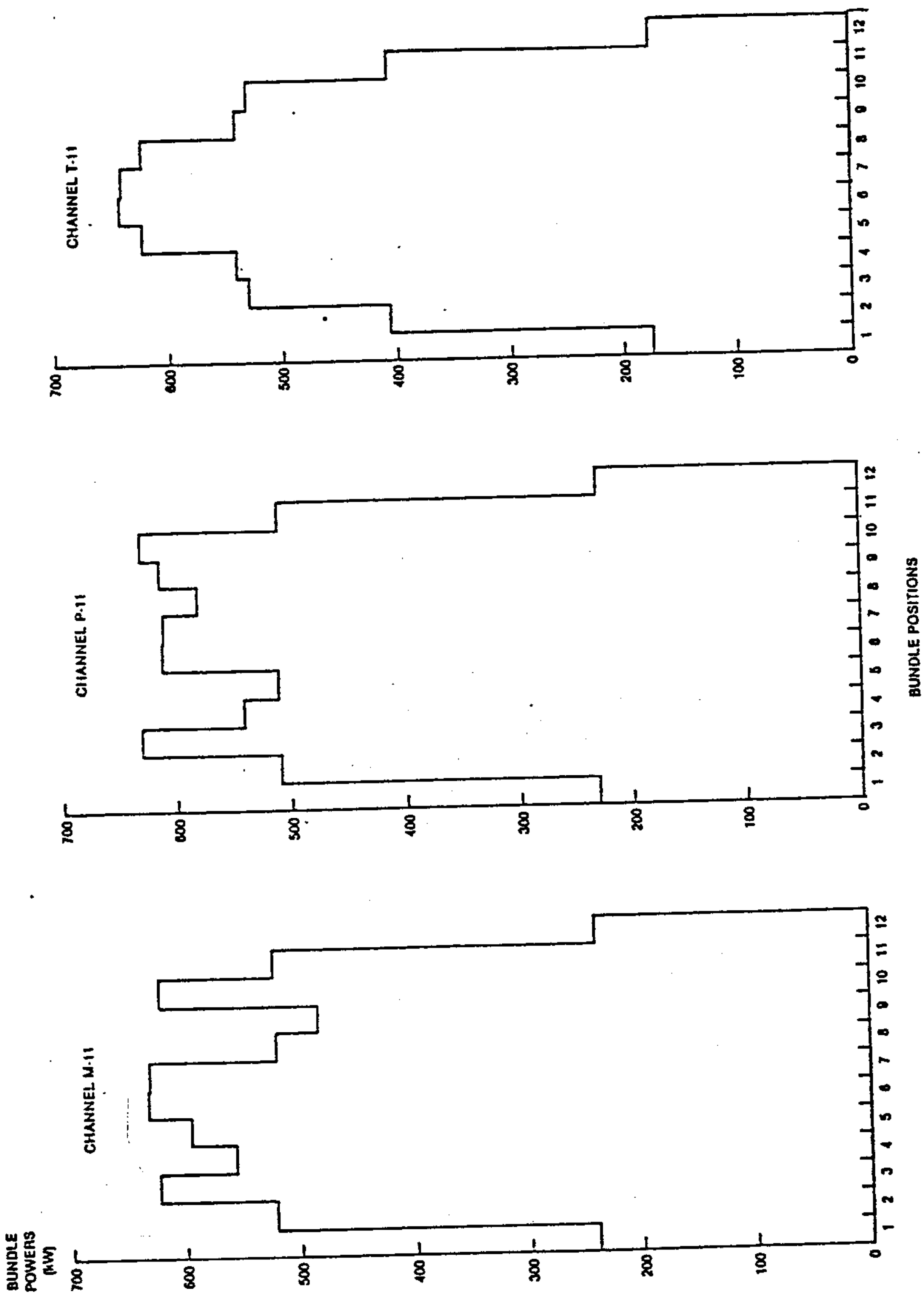

FIGURE 4.3-11 AXIAL BUNDLE POWER DISTRIBUTION AT 100 FPD

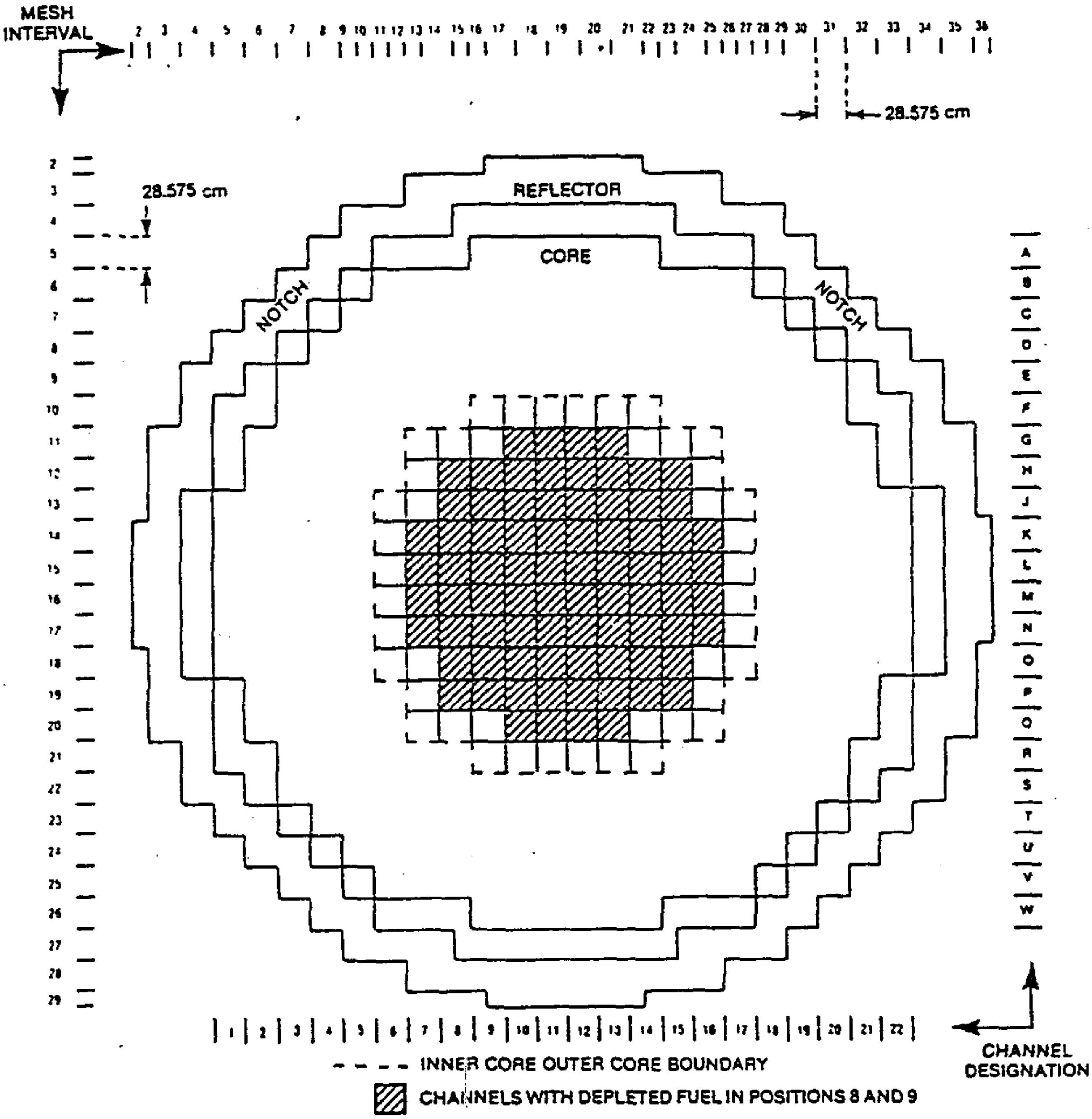

FIGURE 4.3-13 600 MW REACTOR MODEL FACE VIEW SHOWING INITIAL LOADING OF DEPLETED FUEL